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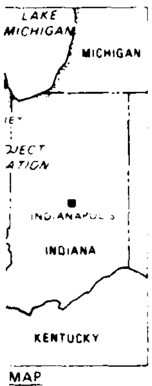

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TECHNICAL REPORT HL-89-1

SUBMERSIBLE-TYPE TAINTER GATE FOR SPILLWAY MARSEILLES LOCK AND DAM

Hydraulic Model Investigation

by

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A 1:20-scale hydraulic model simulated a 120-ft-wide section of the spillway and stilling basin including one freely suspended 60-ft-wide by 16-ft-high submersible tainter gate. The gate lifting mechanism consisted of a cable at each end of the gate attached to load cells. The magnitude and frequency of the forces acting on the cable supporting each end of the gate were measured. Tests indicated that there was a likelihood of the cables being subjected to exciting forces occurring at a random frequency with flow (a) over and (b) under the subject gate. The magnitude of these forces was about 1 percent of the total gate weight. Discharge characteristics and coefficients and stilling basin performance with various operating scenarios were determined.

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PREFACE

The model investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers (USACE), on 25 January 1985 at the request of the US Army Engineer District, Rock Island (NCR). The studies were conducted in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) during the period January to October 1985 under the direction of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., and G. A. Pickering, past and present Chiefs of the Hydraulic Structures Division. Tests were conducted by Mrs. D. R. Cooper, Mr. E. L. Jefferson, and Mrs. J. A. Flowers, Spillways and Channels Branch, under the direct supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. This report was prepared by Mrs. Cooper.

During the course of the investigation, Messrs. B. McCartney of USACE; J. Ordonez, B. Snowden, and H. Stuart of the US Army Engineer Division, North Central; and S. K. Nanda, D. Wehrley, D. McCully, and J. Schliekelman of NCR visited WES to discuss test results and correlate these results with current design studies.

Special thanks to Mrs. M. C. Gay, Information Technology Laboratory, WES, who edited this report; Mr. R. T. Blackwell, Engineering and Construction Services Division, WES, who constructed the gate; and Mr. J. L. Grace, Jr., who provided technical guidance during this study.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

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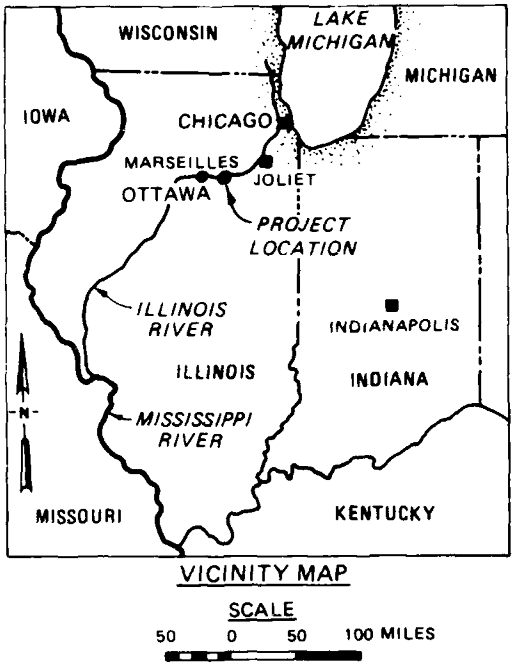
CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
inches	25.4	millimetres
miles (US statute)	1.609344	kilometres
pounds (force)	4.448222	newtons
pounds (mass)	0.45359	kilograms



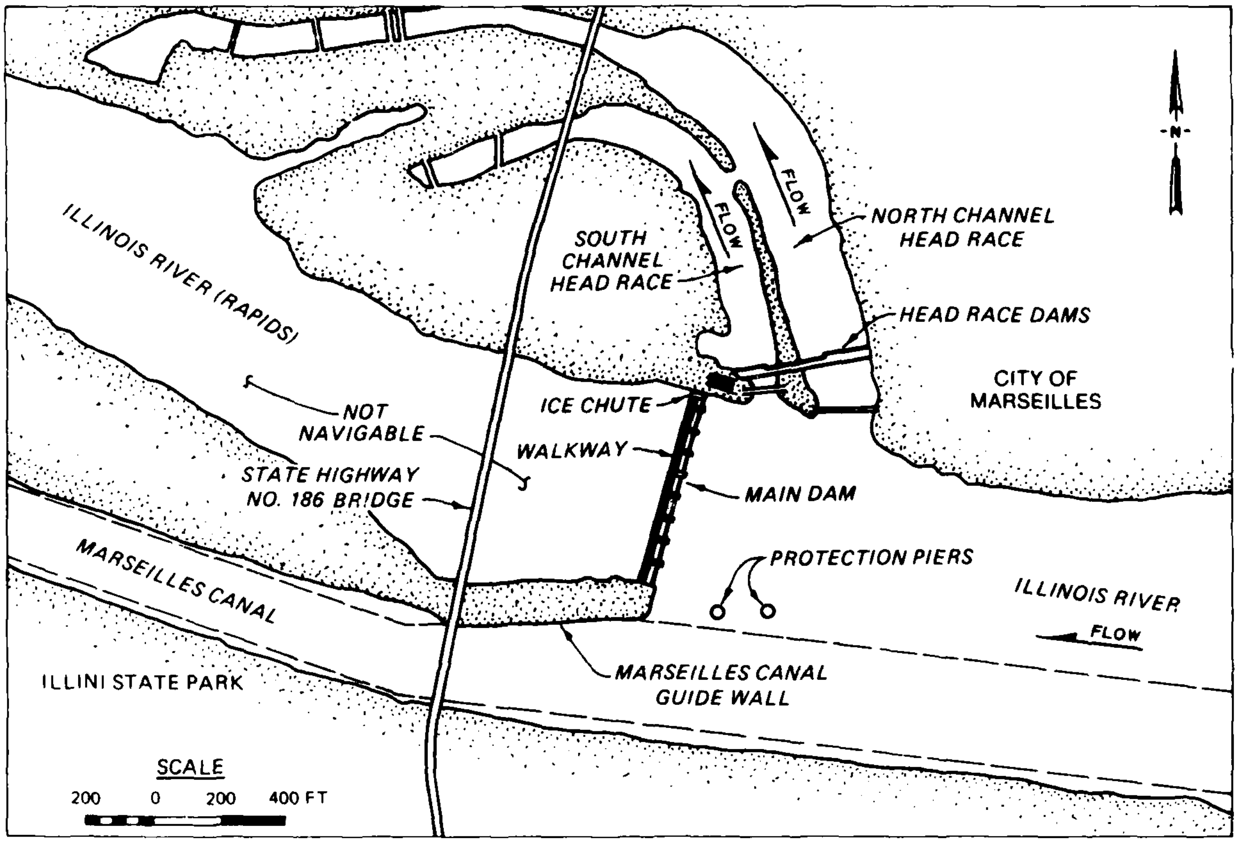


Figure 1. Vicinity and location map

SUBMERSIBLE-TYPE TAINTER GATE FOR SPILLWAY
MARSEILLES LOCK AND DAM
Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. Marseilles Dam is located at the upstream end of the Marseilles Canal at river mile 247.0 on the Illinois River, near the city of Marseilles, IL, approximately 6 miles* southeast of the city of Ottawa and 65 miles southwest of Chicago, IL (Figure 1). The lock is located at the mouth of the Marseilles Canal 2.4 miles downstream of the dam at river mile 244.6. The lock and dam are connected by Bells Island.

2. The main dam is a gated structure founded on shale spanning the Illinois River at the upstream end of the Marseilles Canal (Figure 1). At the time this model investigation was performed, the main dam consisted of a 552-ft-wide section containing eight counterweighted nonsubmersible 60-ft-wide tainter gates and a 46.5-ft-wide section containing a 30-ft-wide ice chute and a 16.5-ft-wide ice chute valve room (Plate 1). The normal head on the main dam is about 13 ft and the upper pool is maintained at el 483.17.** The spillway tainter gates are 16 ft high with a radius of 25 ft (Plate 2). Connected by two counterweighted side arms, each gate revolves about two trunnions located in adjacent piers at the origin of the gate radius.

3. To bring the dam up to current design standards, and provide a safe and reliable operation, the US Army Engineer District, Rock Island, proposed to replace the counterweighted, nonsubmersible tainter gates of the main dam with new submersible tainter gates (Plate 3). All eight of the prototype submersible tainter gates have been installed at Marseilles Dam. The new gates are designed to pass water under the gate as at present (Photo 1), or over the gate with a maximum 8 ft of gate submergence (Photo 2). During high flows,

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* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 3.

** All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

the gates may be raised completely out of the water.

4. The submergence feature of the gates will permit skimming ice and debris over the top of the gate with a much smaller water discharge than would be required to draw the material under a nonsubmersible type gate. Year-round operation requires passage of quantities of ice and, to a lesser extent, debris through the dam when flow in the river is insufficient to permit raising gates clear of the water surface without a serious loss of pool levels. Flow sufficient to skim floating material over the top of a submerged gate should produce less violent downstream effects.

Purpose and Scope of the Model Study

5. Because US Army Corps of Engineers submersible gates on the Ohio River have historically experienced severe vibrations,* this model study was conducted to determine the magnitude and frequency of the hydraulic forces acting on the lifting cables while the gate is submerged. In addition, verification of anticipated stilling basin performance for all probable operating conditions was of interest. Discharge characteristics and coefficients with various operating scenarios were determined from the model.

* US Army Engineer District, Louisville. 1985 (Jun). "Submergible Gate Use Within the Corps: Case Histories," Louisville, KY.

PART II: THE MODEL AND TEST PROCEDURE

Description

6. The 1:20-scale model (Figure 2) reproduced a 120-ft-wide section of the spillway and stilling basin including one freely suspended 60-ft-wide by 16-ft-high submersible tainter gate, two 8-ft-wide piers, and two 22-ft-wide by 16-ft-high portions of the tainter gate on either side of the piers. The model tainter gate (Figure 3) was constructed of brass and simulated a prototype weighing 160,000 lb (dry weight). The upstream and downstream skinplates and trunnion arms were reproduced to scale. Originally the rubber side seals were omitted, simulating a 4-in. gap between the gate and the piers. This provision was made to avoid friction between the gate and piers and was part of the type 1 and 2 designs. However, this provision proved to be too significant a deviation from the prototype and was responsible for most of the vibration reported herein. To reduce friction forces to a minimum, the gate trunnions were mounted in roller bearings in the adjacent piers. The gate-to-sill clearance simulated was 1 in. The piers and ice deflector shields (Plate 3) were constructed of transparent plastic; the portion of the model representing the spillway sill and apron was fabricated of sheet metal. The two adjacent gates were simulated schematically and reproduced only the shape and size of a nonsubmersible-type tainter gate. The gate lifting mechanism consisted of a cable at each end of the gate attached to load cells suspended by a pulley system (Figure 2). Each model cable was sized to reproduce the elastic properties of four prototype cables proposed for each end of the gate.

Appurtenances and Instrumentation

7. Water used in the operation of the model was supplied by pumps, and discharges were measured with venturi meters. The tailwater in the downstream end of the model was controlled by an adjustable tailgate. Steel rails set to grade provided reference planes. Water-surface elevations were obtained with point gages. Velocities were measured with a pitot tube. Load cells and an oscillograph recorder (Figure 4) were used to measure and record the magnitude and frequency of the total forces acting on each end of the gate. Chart speed used during testing was 1 ips.

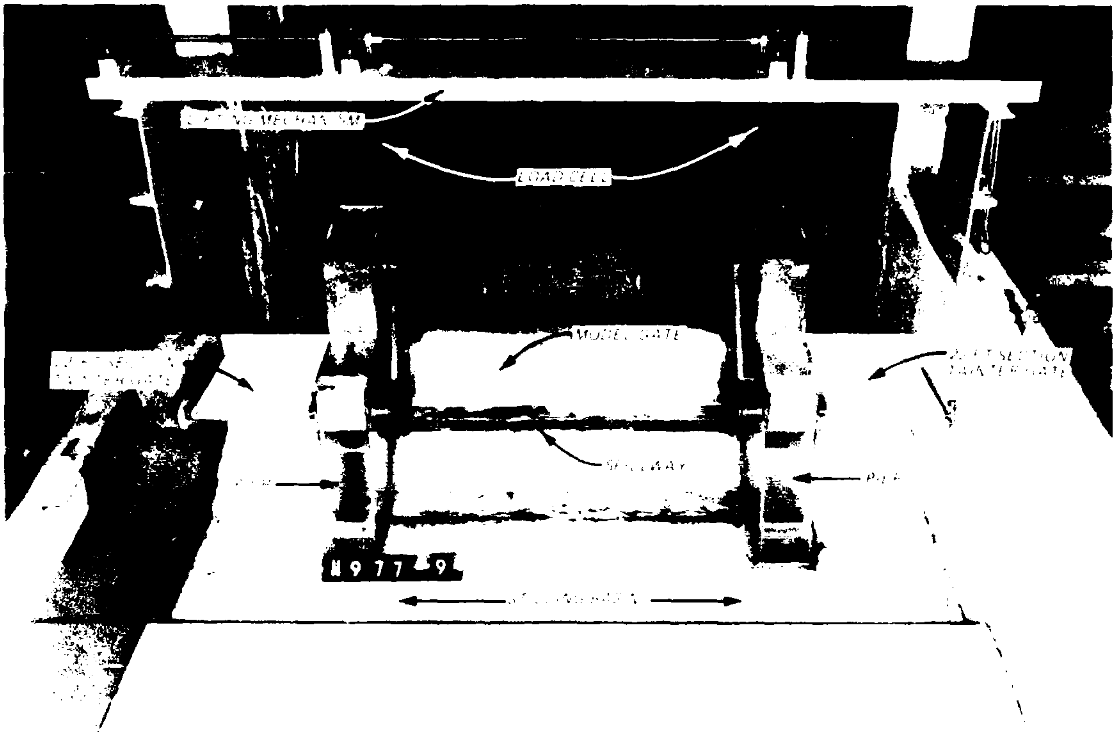


Figure 2. 1:20-scale model

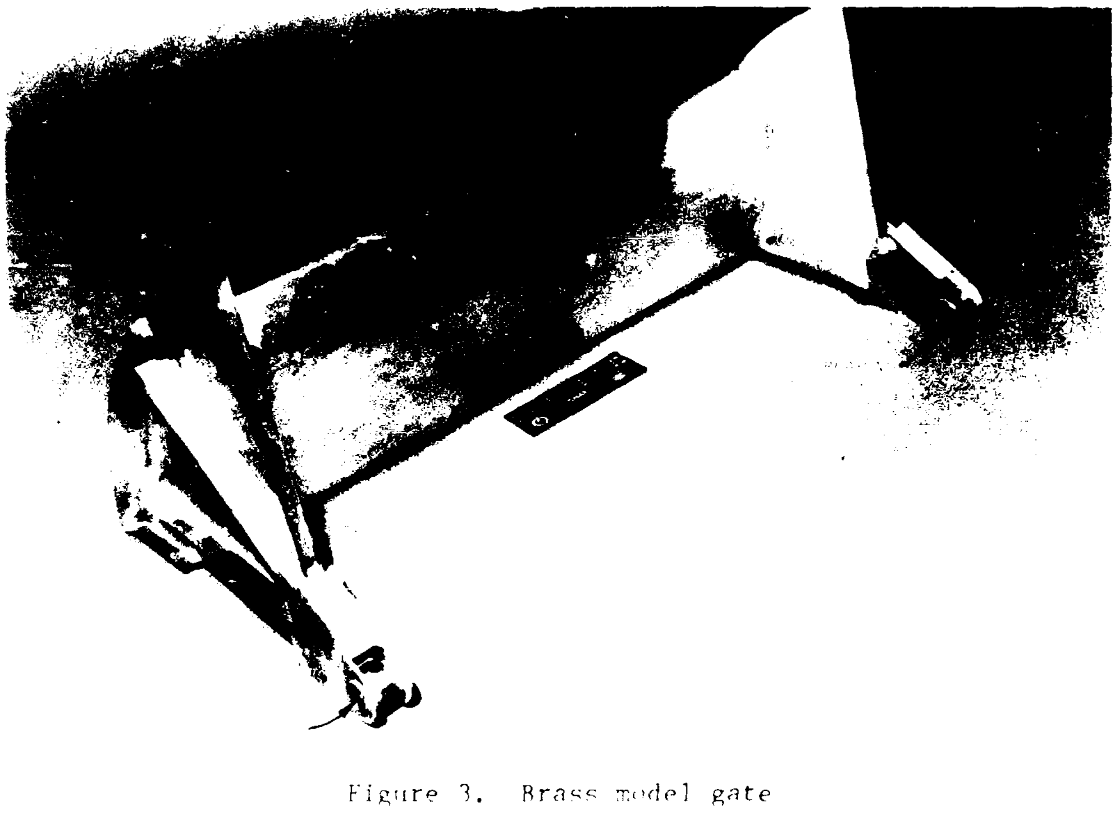


Figure 3. Brass model gate

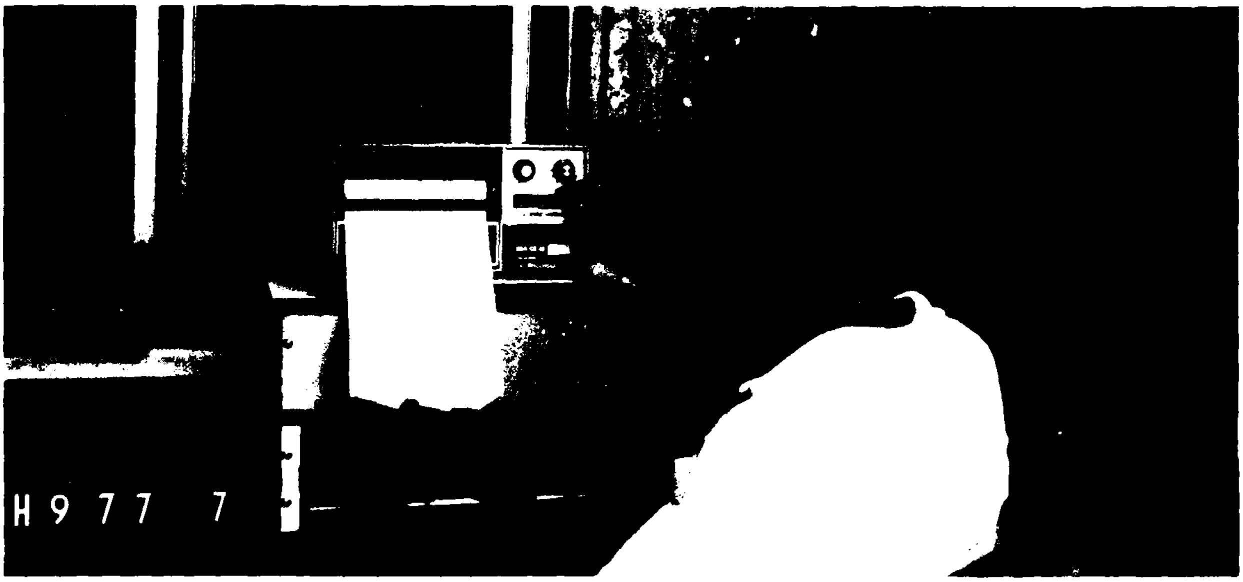


Figure 4. Oscillograph recorder

Scale Relations

8. The accepted equations of hydraulic similitude, based upon the Froude relations, were used to express the mathematical relations between the dimensions and hydraulic quantities of the model and the prototype. General relations for transference of model data to prototype equivalents are presented in the following tabulation:

Dimension	Ratio	Scale Relation
Length	$L_r = L$	1:20
Area	$A_r = L_r^2$	1:400
Velocity	$V_r = L_r^{1/2}$	1:4.472
Time	$T_r = L_r^{1/2}$	1:4.472
Discharge	$Q_r = L_r^{5/2}$	1:1,788.85
Weight	$W_r = L_r^3$	1:8,000
Force	$F_r = L_r^3$	1:8,000

Test Procedure

9. Tests were conducted in the model to observe the conditions with

flow over and under the gate and to determine the magnitude and frequency of the hydraulic forces acting on the lifting cables with various gate openings and submergences of the gate. To measure the forces on the gate, the pool elevation was held constant while the position of the gate and the tailwater were varied.

10. All tests were conducted with the upper pool level maintained at a constant elevation of 483.17. Prior to the start of a test, the force-measuring equipment was checked to ensure that it was working properly, the moving parts of the test gate were examined, and the water levels of the upper pool and the lower pool below the gate were properly adjusted. The force-measuring device, having previously been zeroed, was then placed in operation (raising or lowering the test gate). The force on the hoisting cables was measured by raising the crest of the gate in 1-ft increments to a desired elevation and holding it there for a measurement. All force data presented in the tables in this report were measured in this manner.

Presentation of Data

11. In the presentation of test results, the data are not provided in the chronological order in which the tests were conducted. Instead, as each element of the gate and the gate lifting mechanism is considered, all tests conducted thereon are discussed. All model data are presented in terms of prototype equivalents. All tests are discussed in Part III.

PART III: TESTS AND RESULTS

12. Tests were conducted with two different spillway crest designs for the submersible-gated spillway. These designs, furnished by the sponsor, differed only in the shape of spillway crest upstream from the gate. The type 1 (original) design (Plate 4) had a curved shape with an 8-ft radius, and the type 2 design had a 2.5-ft-broad horizontal sill preceded by a 1V on 1.2H sloping face (Plate 4). Tests were conducted to determine discharge characteristics, stilling basin performance, loads on the gate lifting cables, and vibration tendencies of the gate with each of these crest shapes. Tests were also conducted to determine the effects on the cable loads and vibration tendencies of decreasing the clearance between the gate and pier and increasing the gate-to-sill clearance.

Discharge Characteristics

Flow conditions

13. Tests to determine the discharge characteristics of the spillway with the two spillway crest designs were conducted for each of the following flow conditions:

- a. Free uncontrolled flow. Gate fully open; upper pool unaffected by the tailwater.
- b. Submerged uncontrolled flow. Gate fully open; upper pool controlled by the submergence effect of the tailwater.
- c. Free uncontrolled flow (over the gate). Gate in submerged position with flow over gate; upper pool unaffected by the tailwater. Gate essentially behaves as a weir fixed at several elevations.
- d. Submerged uncontrolled flow (over the gate). Gate in submerged position with flow over the gate; upper pool controlled by the submergence effect of the tailwater. Gate essentially behaves as a weir fixed at several elevations.
- e. Free controlled flow. Gate partially open; upper pool unaffected by the tailwater; controlled by the particular gate opening with flow under the gate.
- f. Submerged controlled flow. Gate partially open; upper pool controlled by both the submergence effect of the tailwater and the gate opening with flow under the gate.

These flow regimes are shown in Plate 5. Symbols used in this plate are defined in paragraph 18.

Description of tests

14. Free uncontrolled flow characteristics were determined by introducing various constant discharges into the model and observing the corresponding upper pool elevation. Sufficient time was allowed for stabilization of the upstream flow conditions. Upper pool elevations were measured at a point 180 ft upstream from the spillway. Tailwater elevations were measured at a point 300 ft downstream of the end sill.

15. A similar procedure was followed for gate openings ranging from 2 to 8 ft to determine the discharge characteristics of free controlled flow.

16. Submerged flow characteristics for both controlled and uncontrolled flows were determined by introducing several constant discharges into the model and varying the tailwater for each discharge from an elevation at which no interference with spillway flow was evident to an elevation at which the flow was practically 100 percent submerged. The elevation of the upper pool for each tailwater elevation was recorded.

Presentation and analysis of data

17. Basic data obtained with flow over the spillway are presented in plots of upper pool elevation versus tailwater elevation for each of the spillway crest designs. These data for the type 1 (original) design spillway crest and type 2 design spillway crest are shown in Plates 6-10 and 11-15, respectively. Free flow data with flow over the gate are shown in Plates 16 and 17 for the two spillway crest shapes. Data showing the effect of tailwater elevation on discharge with flow over the gate are shown in Plates 18 and 19 for the two spillway crest shapes. It should be noted that with flow over the gate, there was also some flow through the gaps between the end of the gate and the piers and through the clearance between the gate and spillway crest. Because the modeled gate-to-pier clearances of the type 2 and 3 design structures differed by 3-1/2 in. (less than 3/16 in. in the model), there was very little difference in the flow characteristics of each design.

18. The following flow conditions and equations were used to satisfy the calibration data:

a. Free uncontrolled flow:

$Q = CLH^{3/2}$, where C is a function of H

b. Submerged uncontrolled flow:

$Q = C_1 LH^{3/2}$, where C_1 is a function of h/H

c. Free uncontrolled flow (over the gate):

$Q = C_c L_c H_c^{3/2}$, where C_c is a function of H_c

d. Submerged uncontrolled flow (over the gate):

$Q = C_{c_1} L_c H_c^{3/2}$, where C_{c_1} is a function of h_c/H_c

e. Free controlled flow:

$Q = C_g L G_o \sqrt{2gH_g}$, where C_g is a function of H_g and G_o

f. Submerged controlled flow:

$Q = C_{g_s} Lh \sqrt{2g\Delta H}$, where C_{g_s} is a function of h/G_o

Symbols used in these equations are defined as follows:

Q = total discharge, cfs

L = net length of spillway crest, ft

H = gross head on spillway crest, ft

h = depth of tailwater above spillway crest, ft

L_c = net length of gate crest, ft

H_c = gross head on gate crest, ft

h_c = depth of tailwater above gate crest, ft

G_o = gate opening, ft

g = acceleration due to gravity, ft/sec^2

H_g = gross head on gate $(H - 1/2G_o)$, ft

ΔH = differential between gross head on spillway crest and depth of tailwater referenced to spillway crest $(H - h)$, ft

Effect of spillway crest shape on discharge characteristics

19. Discharge coefficients for free uncontrolled flows over the spillway weir with various gross heads on the weir are shown for the two spillway crest designs investigated in Plates 20 and 21. These data have a reasonable degree of scatter and indicate that the shape of the spillway approach face had very little effect upon the discharge characteristics of free uncontrolled flows.

20. The effect of tailwater submergence for uncontrolled flow over the spillway weir was determined by plotting the percent of submergence (h/H) versus a percent reduction in the free flow coefficient (C_1/C) as shown in

Plates 22 and 23 for the two weir shapes. As those plots indicate, the C_1/C value approaches unity at an h/H value of about 0.6; thus free flow conditions exist with values smaller than this. The data indicate that the shape of the weir crest had little effect on the submerged uncontrolled flow characteristics.

21. Discharge coefficients for free uncontrolled flow over the gate with various heads on the gate crest are shown in Plates 24 and 25 for the two spillway weir shapes. As expected, the spillway weir shape had no effect on these discharge coefficients.

22. The effect of tailwater submergence for uncontrolled flow over the gate is shown by the coefficients in Plates 26 and 27. Again, the spillway weir shape had no effect on these coefficients.

23. Relations between the free controlled flow discharge coefficient and gross head on the gate for various gate openings and the two spillway crest designs are presented in Plates 28 and 29. These data indicate that the shape of the spillway face and crest has little effect upon the discharge characteristics of this type of flow. Discharge-head relations are presented for free flow in Plates 30 and 31.

24. Submerged controlled flow discharge coefficients versus the ratio of tailwater depth above the crest to gate opening for each spillway crest design are shown in Plates 32 and 33. A comparison of these two plates indicates that the shape of the spillway face and crest has no effect on the discharge characteristics of submerged controlled flow within the limits investigated.

25. It was concluded from the data obtained with the gate raised out of the flow, with the gate submerged so that flow passed over the gate, and with the gate raised to allow flow underneath, that the spillway weir shapes tested had very little effect on discharge characteristics of the Marseilles Dam. The data were used to construct plots of discharge versus tailwater elevation for the normal upper pool elevation of 483.17 with flow underneath various gate openings. These plots are shown in Plates 34 and 35. The same type of plot with flow over the gates is shown in Plates 18 and 19.

Flow regimes

26. An analysis of the data was made to define the limits of each flow regime and corresponding discharge equation. The results of efforts to distinguish between free and submerged uncontrolled flows over the spillway,

shown in Plate 36, illustrate that in general, free uncontrolled flow becomes submerged uncontrolled flow for tailwater submergences equal to or greater than 60 percent.

27. The difference between free uncontrolled and submerged uncontrolled flows with flow over the gate can be determined from Plate 37.

28. Plate 38 indicates that free and submerged controlled flows can be distinguished by the degree of submergence.

29. To define the limits of free controlled and free uncontrolled flows, tests were made with several gate openings and free flow tailwater conditions in which the head on the weir and the discharge were decreased until the nappe separated from the gate. Observations indicated that free controlled flow became free uncontrolled flow when the ratio of H/G_o was equal to or less than 1.2.

30. Similar investigations for submerged flows indicated that submerged controlled flows became submerged uncontrolled flows when the ratio of h/G_o was equal to or less than 1.0 for ratios of $(H - h)/G_o$ less than 0.3 (Plate 39). In distinguishing between those flow regimes, it is to be noted that for conditions of h/G_o less than 1.0, the flow may be either submerged uncontrolled, free uncontrolled, or free controlled, depending upon the value of $(H - h)/G_o$. If $(H - h)/G_o$ is less than 0.3, the flow is submerged uncontrolled. If $(H - h)/G_o$ is greater than 0.3 but less than 0.6, the flow is free uncontrolled. If $(H - h)/G_o$ is greater than 0.6, the flow is free controlled.

Stilling Basin Performance

Type 1 spillway crest

31. Initial tests were concerned with the hydraulic performance of the original (type 1) spillway crest (Plate 4) with gate openings of 2, 4, 5, 7, and 9 ft and an upper pool elevation of 483.17. For each of these conditions and tailwater depths ranging from minimum to maximum, the stilling basin action was observed, the type of jump recorded, and velocities measured at a point 1 ft above the exit channel bottom 27 ft downstream of the end sill. Data on stilling basin performance below the original spillway (type 1) are given in Plate 40.

Type 2 spillway crest

32. The hydraulic performance of the type 2 spillway crest (Plate 4) was investigated with the same gate openings and upper pool elevation as for type 1. Velocities were measured for each of these conditions and tailwater depths ranging from minimum to maximum and the resulting jump recorded. Data on stilling basin performance below the type 2 spillway are given in Plate 41. The spillway crest shape had very little effect on stilling basin action and velocities downstream from the structure.

33. As requested by the Rock Island District, the depth of flow entering the stilling basin d_1 and the tailwater depth d_2 were measured at minimum tailwater conditions for various gate openings. The depth of flow entering the stilling basin d_1 and the depth of tailwater d_2 were measured as indicated in Figure 5. The d_1 depth was measured 10 ft downstream of the spillway crest above the toe of the spillway. The d_2 depth was measured 46 ft downstream of the spillway crest center line, 1 ft upstream of the stepped end sill. These values are tabulated in Table 1 for gate openings of 2, 4, 5, and 7 ft and 2, 5, 7, and 8 ft of submergence.

Gate Cable Loads and Vibrations

Original (type 1) design structure

34. The original designs for the spillway and submersible tainter gate were described in paragraph 6; general dimensions are shown in Plate 3.

35. Initial tests were conducted to assure that the natural frequency of the model cables was not in the range of the natural frequency of the exciting forces measured in the model. The prototype cable natural frequency was estimated by the R ck Island District to be 4.5 Hz.

36. Forces induced in the gate lifting cables by flow (a) under and (b) over the subject gate were measured with a normal upper pool (el 483.17) in combination with various tailwater elevations. The test procedure is described in paragraph 10. A profile sketch and definitions of terms are presented in Plate 42. A sample oscillograph record and sample calculation are presented in Plate 43. Test results are tabulated in Tables 2 and 3.

37. During tests an undular jump or "rooster tail" developed immediately downstream of the gate with several combinations of gate openings and tailwater elevations with a normal upper pool (el 483.17) (Photo 3).

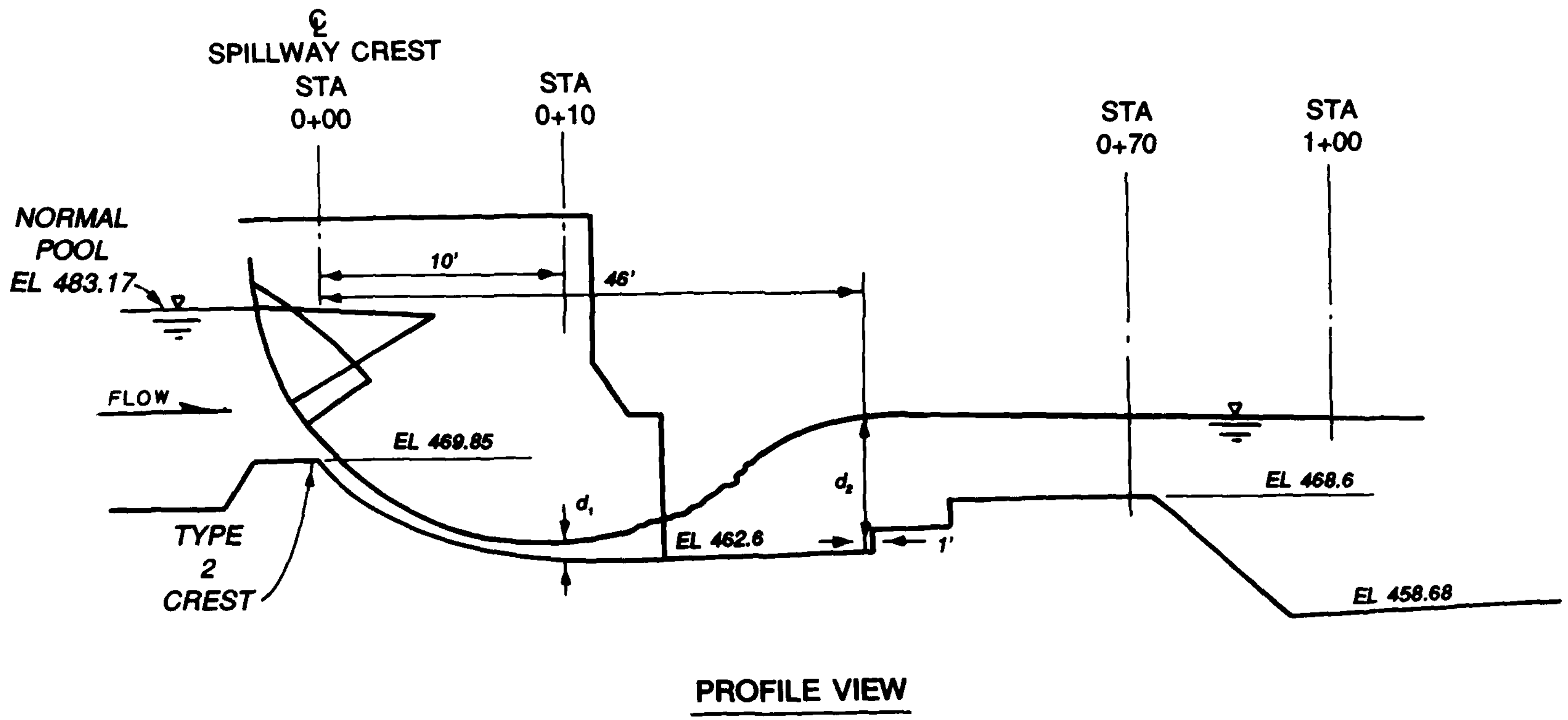


Figure 5. Locations of d_1 and d_2 measurements

Vibrations of the gate with flow under the gate were recorded with these conditions. The model test results indicated that the original (type 1) design structure will likely permit the gate cables to be subjected to loads occurring at a random frequency during normal operations with flow under small gate openings due to the contact of the gate with flow (Photo 4). The magnitude of these vibrations, however, is very small (less than 3 percent) compared to the gate's weight. With flow over the type 1 design structure, the likelihood of forces acting on the cables at a periodic frequency was indicated for essentially all submergences and expected headwaters and tailwaters, as shown in Table 3. The frequency of the induced forces (1.6-3.4 Hz) is considered unacceptably close to the natural frequency of the prototype lifting cables (4.5 Hz). Because of the proximity of the frequency of the flow-induced loads on the cables to the natural frequency of the prototype cables, the type 1 design structure (Plate 3) was considered unstable.

Type 2 design structure

38. The type 2 design structure consisted of the type 2 spillway crest and the type 1 gate.

39. Forces induced in the gate lifting cables by flow (a) under and (b) over the gate were measured with a normal upper pool (el 483.17) in combination with various tailwater elevations. Test results are tabulated in Tables 4 and 5.

40. The tests indicated that the type 2 design structure will likely permit the gate cables to be subjected to loads occurring at a random frequency during normal operations with flow under small gate openings due to contact of the gate with flow. The magnitude of these vibrations, however, is very small (less than 2 percent) compared to the gate's weight. With flow over the type 2 design structure (Photo 5), the likelihood of forces acting on the cables at a periodic frequency was indicated for gate submergences of up to and including 6 ft. There was some reduction in the frequency and magnitude of the periodic vibrations with the type 2 design structure. Loads began to occur at a random frequency for gate submergences of 7 and 8 ft (fully submerged). The incidence of the reported vibration is primarily attributable to the large gap at the sides of the gate as evident in comparing the results from tests of the type 2 design with those of the type 3 design. The side seal gap was decreased to eliminate the vibrations with flow over the gate.

Type 3 design structure

41. The type 3 design structure incorporated the type 2 design spillway crest and the type 2 design gate (extension of the gate end shields to decrease the gate-to-pier clearance from 4 in. to 1/2 in., while maintaining a gate-to-sill clearance of 1 in.).

42. Forces induced in the gate lifting cables by flow (a) under and (b) over the gate were measured with a normal upper pool (el 483.17). The results are tabulated in Tables 6 and 7.

43. The tests indicated that the type 3 design structure will likely permit the gate cables to be subjected to loads occurring at a random frequency during normal operations with flow under small gate openings due to contact of the gate with flow. The magnitude of these vibrations, however, was very small (about 1 percent) compared to the gate's weight. With flow over the type 3 design structure, the forces acting on the cables occurred at a random frequency for submergences of 2, 5, 6, and 7 ft. The gate cables were not subjected to any vibrations for most gate submergences.

44. Because of the likelihood of the occurrence of random vibrations during normal operations of the gate with flow (a) under or (b) over the gate, the US Army Engineer Waterways Experiment Station (WES) suggested a brace to physically hold or "lock" the gate into position. A friction shoe (Plate 44) that could be installed on each side of the gate between the gate and pier was designed by the Rock Island District and was tested in the model. Although tests with the friction shoe indicated essentially no occurrence of vibrations, there is some doubt that these results are anything but qualitative because the friction in the model supplied by the friction shoe cannot be directly scaled to simulate prototype friction. The value of a friction shoe is that it provides a factor of safety in the event that vibrations do occur. Therefore, the type 3 design structure with a friction shoe installed on each side of the gate was recommended for prototype construction. The Rock Island District, however, opted not to include the friction shoe in the construction contract for the submersible tainter gates with the following rationale. The total amplitude, Δ_p, of the highest load fluctuation measured in the model was 1,500 lb. Only one-half of that load fluctuation would have to be overcome by friction to negate the exciting forces and prevent vibration (Plate 43). One-half of that, or 375 lb, would have to be overcome by friction on each side of the gate. A conservatively low estimate of the prototype

trunnion friction on each side of the prototype gate is 600 lb. The side seal friction at each side of the prototype is estimated at 3,000 lb, giving a significant factor of safety. In addition, the load fluctuations in the model all acted at random frequencies rather than at periodic frequencies; thus, the deflection in the cables will not build resonantly. The first of the prototype gates was put in operation in January 1987, and the last (eighth) gate was put in operation in March 1988. All of the prototype submersible tainter gates are operating vibration free.

Type 4 and 5 design structures

45. The type 4 design structure incorporated the type 2 design spillway crest shape and the type 2 design gate (extension of the gate end shields to decrease the gate-to-pier clearance from 4 in. to 1/2 in., while maintaining a gate-to-sill clearance of 1/2 in.). The type 5 design structure differed from the type 4 design structure only in the gate-to-sill clearance. The gate-to-sill clearance of the type 5 design structure was 3 in. Cursory tests were conducted on these two designs to examine the relationship between gate-to-sill clearance and the tendency for periodic or larger load fluctuations in the gate cables. Because the 1/2-in. gate-to-sill clearance was so small (in the model less than 1/32 in.), tests to determine the effect on the occurrence of vibrations are not considered valid. There was an increase, however, in the occurrence, magnitude, and frequency of the load fluctuations when the gate-to-sill clearance was increased to 3 in. (with the type 5 design structure). Therefore, it was concluded that the increased gate-to-sill clearance increased the tendency for larger periodic vibrations based on these tests. Further study, however, is required to examine specific factors that affect vibrations of submersible tainter gates.

46. The tendency and frequency of vibrations increased at the smaller gate submergences (1-3 ft) and lower tailwater elevations (el 470-472). The smaller gate submergences produced unstable conditions because of the almost equal amounts of flow under and over the gate. As the tailwater increased, the flow under the gate (between the gate and sill) decreased and the magnitude and frequency of vibrations decreased.

PART IV: CONCLUSIONS

47. Results of tests to determine discharge characteristics of the Marseilles Dam with two spillway crest designs indicated six possible flow conditions, which can be satisfied by the following equations:

a. Free uncontrolled flow (over the spillway):

$Q = CLH^{3/2}$, where C is a function of H as shown in Plates 20 and 21.

b. Submerged uncontrolled flow (over the spillway):

$Q = C_1 LH^{3/2}$, where C_1 is a function of h/H as shown in Plates 22 and 23.

c. Free uncontrolled flow (over the gate):

$Q = C_c L_c H_c^{3/2}$, where C_c is a function of H_c as shown in Plates 24 and 25.

d. Submerged uncontrolled flow (over the gate):

$Q = C_{c_1} L_c H_c^{3/2}$, where C_{c_1} is a function of h_c/H_c as shown in Plates 26 and 27.

e. Free controlled flow:

$Q = C_g L G_o \sqrt{2gH_g}$, where C_g is a function of H_g and G_o as shown in Plates 28 and 29.

f. Submerged controlled flow:

$Q = C_{g_s} Lh \sqrt{2g\Delta H}$, where C_{g_s} is a function of h/G_o as shown in Plates 32 and 33.

The spillway crest shape had little or no effect on the discharge characteristics of the structure.

48. Stilling basin performance tests and velocities measured downstream from the basin indicated that the spillway crest shape had little effect on basin performance.

49. Testing of the type 3 design structure (a 2.5-ft-broad horizontal sill preceded by a 1V on 1.2H sloping face and a gate with 1/2-in. gate-to-pier clearance) indicated the gate cables to be subject to load fluctuations occurring at a random frequency during normal operations with flow under small

gate openings due to contact between the gate and the water surface. The magnitude of these vibrations, however, was only about 1 percent of the gate's total weight. Based on the gate's performance in the prototype, mathematically speaking, the prototype cables would not detect these load fluctuations because these vibrating forces are less than the combination of the prototype trunnion and side seal friction. The forces acting on the cables occurred at a random frequency for gate submergences of 2, 5, 6, and 7 ft with flow over the gate. There were no periodic vibrations.

50. Because of the likelihood of the occurrence of random vibrations during normal operations of the gate with flow (a) under or (b) over the gate, a friction shoe between the gate and pier was tested in the model. Although tests with the friction shoe indicated essentially no occurrence of random or periodic vibrations, there is some doubt that these results are anything but qualitative because the friction in the model supplied by the friction shoe cannot be directly scaled to simulate prototype friction. The value of the friction shoe tests is the indication that such a "dogging" device <u>can be designed and is useful in eliminating vibrations that may occur</u>. The shoe introduces a factor of safety for dampening out the random vibrations of the Marseilles gate cables. Therefore, the type 3 design structure with friction shoe was recommended by WES for prototype construction. The Rock Island District elected not to use the friction shoe, which could have been used if vibration was noted in the prototype. However, the magnitude of the exciting forces was small compared to the total cable load and the trunnion and side seal friction. The District reports that the eight new Marseilles Dam prototype submersible tainter gates are in operation without any noticeable vibration.

51. Tests indicated that at smaller gate submergences and lower tailwater elevations, vibrations were more likely to occur at a periodic frequency. Further, a direct relationship was established between increased gate-to-sill clearance and an increase in magnitude and frequency of gate vibrations. As the gate-to-sill clearance increased, the tendency for increased and more periodic vibrations also increased.

Table 1

d_1 and d_2 Values

Type 2 Spillway Crest

Pool El 483.17, Tailwater El 470.00

G_o ft*	Q cfs	d_1 ft	d_2 ft
2	2,700	6.9	8.2
4	4,100	7.1	9.4
5	5,000	7.8	10.0
7	6,320	10.3	10.7
-2	500	7.5	7.7
-5	1,800	8.2	8.6
-7	3,200	8.4	9.7
-8	3,850	9.2	10.6

* Negative values represent the amount of gate submergence.

Table 2

Gate Cable Loads and Vibrations

Type 1 (Original) Design Structure

Flow Under Gate

G_o ft	TW EL	F_2 lb	F_3 lb	F_4 lb	F_{5max} lb	F_{5min} lb	f Hz	Λ_p lb
1	470	0	115,300	153,200	37,900	36,400	RANDOM	1,500
1	473	5,200	110,100	164,800	54,700	54,100	RANDOM	600
1	474	7,400	107,900	161,900	54,000	54,000	RANDOM	0
2	470	0	115,300	156,100	40,800	39,300	RANDOM	1,500
2	472	800	114,500	166,200	51,700	51,100	RANDOM	600
2	474	5,200	110,100	164,800	54,700	54,100	RANDOM	600
2	475	7,400	107,900	141,500	33,600	33,000	RANDOM	600
4	470	0	115,300	156,200	40,900	39,400	RANDOM	1,500
4	472	0	115,300	164,800	49,500	48,000	RANDOM	1,500
4	474	800	114,500	163,300	48,800	47,300	RANDOM	1,500
4	476	5,200	110,100	156,200	46,100	44,600	RANDOM	1,500
5	470	0	115,300	162,000	46,700	43,700	RANDOM	3,000
5	474	0	115,300	161,800	46,500	45,000	RANDOM	1,500
5	478	7,400	107,900	161,500	53,600	52,700	RANDOM	900
5	480	10,100	105,200	157,700	52,500	51,600	RANDOM	900
6	470	0	115,300	163,300	48,000	45,400	RANDOM	2,600
6	474	0	115,300	161,800	46,500	45,000	RANDOM	1,500
6	476	800	114,500	163,300	48,800	47,900	RANDOM	900
6	480	9,100	106,200	161,800	55,600	55,600	0	0
7	470	0	115,300	163,800	48,500	47,700	RANDOM	800
7	473	0	115,300	162,100	46,800	46,000	RANDOM	800
7	476	2,900	112,400	162,000	49,600	48,800	RANDOM	800
7	479	5,200	110,100	164,700	54,600	53,700	RANDOM	900
7	481	9,100	106,200	161,600	55,400	53,900	RANDOM	1,500
8	470	0	115,300	163,300	48,000	46,500	RANDOM	1,500
8	473	0	115,300	166,300	51,000	51,000	0	0
8	479	2,900	112,400	158,900	46,500	46,500	0	0
8	482	9,100	106,200	141,300	35,100	35,100	0	0
9	470	0	115,300	164,900	49,600	46,600	RANDOM	3,000
9	472	0	115,300	163,300	48,000	46,500	RANDOM	1,500
9	480	2,900	112,400	163,300	50,900	50,900	0	0
9	483	9,100	106,200	144,300	38,100	38,100	0	0

(Continued)

Note: See Plates 42 and 43 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 2 (Concluded)

G_o ft	TW EL	F_2 lb	F_3 lb	F_4 lb	$F_{5_{max}}$ lb	$F_{5_{min}}$ lb	f Hz	Δ_p lb
10	470	0	115,300	163,300	48,000	46,500	RANDOM	1,500
10	472	0	115,300	167,800	52,500	51,000	RANDOM	1,500
10	478	0	115,300	166,300	51,000	51,000	0	0
10	483	7,400	107,900	147,300	39,400	39,400	0	0

Table 3

Gate Cable Loads and Vibrations

Type 1 (Original) Design Structure

Flow Over Gate

Gate Submergence ft	TW EL	F_2 lb	F_3 lb	F_4 lb	$F_{5\,max}$ lb	$F_{5\,min}$ lb	f Hz	Δ_p lb
1	470	2,900	112,400	132,900	20,500	19,100	3.4	1,400
1	471	5,200	110,100	127,000	16,900	15,500	3.4	1,400
2	470	5,200	110,100	141,600	31,500	30,100	3.1	1,400
2	472	9,100	106,200	132,900	26,700	23,800	2.7	2,900
2	473	10,100	105,200	130,000	24,800	22,800	2.7	2,000
2	475	11,300	104,000	128,500	24,500	22,500	2.2	2,000
3	470	7,400	107,900	144,600	36,700	33,700	2.9	3,000
3	472	10,100	105,200	138,700	33,500	29,500	2.5	4,000
3	474	11,300	104,000	145,800	41,800	38,800	2.5	3,000
3	476	12,450	102,850	131,400	28,550	24,550	2.5	4,000
4	470	9,100	106,200	141,700	35,500	31,500	2.5	4,000
4	472	10,700	104,600	143,100	38,500	34,500	2.5	4,000
4	474	11,850	103,450	138,700	35,250	32,250	2.2	3,000
4	476	13,000	102,300	124,200	21,900	18,900	2.2	3,000
5	470	10,100	105,200	147,100	41,900	38,100	2.2	3,800
5	472	11,300	104,000	145,900	41,900	38,300	2.2	3,600
5	475	13,000	102,300	134,300	32,000	28,500	1.8	3,500
5	478	14,800	100,500	113,800	13,300	9,900	1.8	3,400
6	470	10,700	104,600	144,400	39,800	32,600	1.6	7,200
6	472	11,850	103,450	132,800	29,350	25,850	2.0	3,500
6	476	14,200	101,100	110,800	9,700	8,100	RANDOM	1,600
7	470	11,300	104,000	154,600	50,600	47,100	2.0	3,500
7	472	12,450	102,850	165,000	62,150	56,250	2.0	5,900
7	476	14,800	100,500	117,600	17,100	11,200	1.8	5,900
7	477	15,300	100,000	109,500	9,500	8,100	1.8	1,400
8	470	11,850	103,450	122,700	19,250	16,250	RANDOM	3,000
8	473	13,600	101,700	122,700	21,000	15,100	RANDOM	5,900
8	478	15,300	100,000	58,300	-41,700	-41,700	0	0
8	483	15,300	100,000	49,700	-50,300	-50,300	0	0

Note: See Plates 42 and 43 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 4

Gate Cable Loads and Vibrations

Type 2 Design Structure

Flow Under Gate

G_o ft	TW EL	F_2 lb	F_3 lb	F_4 lb	F_{5max} lb	F_{5min} lb	f Hz	Δ_p lb
1	470	0	115,300	140,100	24,800	24,000	RANDOM	800
1	473	5,200	110,100	147,400	37,300	37,300	0	0
1	474	7,400	107,900	135,700	27,800	27,800	0	0
2	470	0	115,300	158,900	43,600	42,800	RANDOM	800
2	472	800	114,500	148,800	34,300	34,300	0	0
2	474	5,200	110,100	148,800	38,700	38,700	0	0
2	475	7,400	107,900	141,600	33,700	33,700	0	0
4	470	0	115,300	134,300	19,000	17,500	RANDOM	1,500
4	472	0	115,300	141,600	26,300	24,800	RANDOM	1,500
4	474	800	114,500	140,100	25,600	24,100	RANDOM	1,500
4	476	5,200	110,100	137,200	27,100	25,600	RANDOM	1,500
5	470	0	115,300	134,300	19,000	17,500	RANDOM	1,500
5	474	0	115,300	141,600	26,300	24,800	RANDOM	1,500
5	478	7,400	107,900	137,200	29,300	27,800	RANDOM	1,500
5	480	10,100	105,200	119,600	14,400	12,200	RANDOM	2,200
6	470	0	115,300	141,700	26,400	25,700	RANDOM	700
6	474	0	115,300	141,600	26,300	25,600	RANDOM	700
6	476	800	114,500	137,300	22,800	22,100	RANDOM	700
6	480	9,100	106,200	129,700	23,500	21,300	RANDOM	2,200
7	470	0	115,300	135,800	20,500	19,700	RANDOM	800
7	473	0	115,300	134,300	19,000	18,200	RANDOM	800
7	476	2,900	112,400	134,000	21,600	20,800	RANDOM	800
7	479	5,200	110,100	128,300	18,200	17,400	RANDOM	800
7	481	9,100	106,200	116,800	10,600	9,800	RANDOM	800
8	470	0	115,300	127,000	11,700	10,200	RANDOM	1,500
8	473	0	115,300	124,000	8,700	8,000	RANDOM	700
8	479	2,900	112,400	124,000	11,600	10,900	RANDOM	700
8	482	9,100	106,200	105,000	-1,200	-1,200	0	0
9	470	0	115,300	128,500	13,200	11,800	RANDOM	1,400
9	472	0	115,300	124,100	8,800	7,400	RANDOM	1,400
9	480	2,900	112,400	127,000	14,600	13,200	RANDOM	1,400
9	483	9,100	106,200	115,100	8,900	8,900	0	0

(Continued)

Note: See Plates 42 and 43 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 4 (Concluded)

G_o ft	TW EL	F_2 lb	F_3 lb	F_4 lb	$F_{5_{max}}$ lb	$F_{5_{min}}$ lb	f Hz	Δ_p lb
10	470	0	115,300	127,200	11,900	10,400	RANDOM	1,500
10	472	0	115,300	128,500	13,200	13,200	0	0
10	478	0	115,300	127,000	11,700	11,700	0	0
10	483	7,400	107,900	113,900	6,000	6,000	0	0

Table 5

Gate Cable Loads and Vibrations

Type 2 Design Structure

Flow Over Gate

Gate Submergence ft	TW EL	F_2 lb	F_3 lb	F_4 lb	$F_{5_{max}}$ lb	$F_{5_{min}}$ lb	f Hz	Δ_p lb
1	470	2,900	112,400	134,300	21,900	20,500	3.4	1,400
1	471	5,200	110,100	128,500	18,400	17,000	3.4	1,400
2	470	5,200	110,100	140,200	30,100	28,700	3.1	1,400
2	472	9,100	106,200	138,700	32,500	29,600	2.7	2,900
2	473	10,100	105,200	138,600	33,400	30,500	2.5	2,900
2	475	11,300	104,000	128,400	24,400	23,000	2.0	1,400
3	470	7,400	107,900	139,100	31,200	29,000	2.9	2,200
3	472	10,100	105,200	138,400	33,200	31,000	2.5	2,200
3	474	11,300	104,000	138,400	34,400	33,000	2.3	1,400
3	476	12,450	102,850	125,250	22,400	20,200	2.3	2,200
4	470	9,100	106,200	138,700	32,500	29,600	2.7	2,900
4	472	10,700	104,600	138,300	33,700	32,300	2.5	1,400
4	474	11,850	103,450	132,800	29,350	27,950	2.4	1,400
4	476	13,000	102,300	125,600	23,300	20,400	2.4	2,900
5	470	10,100	105,200	143,000	37,800	36,400	2.0	1,400
5	472	11,300	104,000	146,000	42,000	40,600	1.9	1,400
5	475	13,000	102,300	127,300	25,000	23,600	1.7	1,400
5	478	14,800	100,500	124,100	23,600	22,200	1.6	1,400
6	470	10,700	104,600	151,600	47,000	45,600	2.0	1,400
6	472	11,850	103,450	156,200	52,750	51,350	2.0	1,400
6	476	14,200	101,100	148,700	47,600	46,900	RANDOM	700
7	470	11,300	104,000	158,000	54,000	52,600	RANDOM	1,400
7	472	12,450	102,850	163,300	60,450	59,050	RANDOM	1,400
7	476	14,800	100,500	140,200	39,700	38,300	RANDOM	1,400
7	477	15,300	100,000	132,000	32,000	30,600	RANDOM	1,400
8	470	11,850	103,850	127,400	23,550	20,650	RANDOM	2,900
8	473	13,600	101,700	119,300	17,600	16,200	RANDOM	1,400
8	478	15,300	100,000	114,200	14,200	14,200	0	0
8	483	15,300	100,000	103,500	3,500	3,500	0	0

Note: See Plates 42 and 43 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 6

Gate Cable Loads and Vibrations

Type 3 Design Structure

Flow Under Gate

G_o ft	TW EL	F_2 lb	F_3 lb	F_4 lb	$F_{5_{max}}$ lb	$F_{5_{min}}$ lb	f Hz	Δ_p lb
1	470	0	115,300	132,700	17,400	16,600	RANDOM	800
1	473	5,200	110,100	129,800	19,700	19,700	0	0
1	474	7,400	107,900	129,800	21,900	21,900	0	0
2	470	0	115,300	128,400	13,100	12,300	RANDOM	800
2	472	800	114,500	131,300	16,800	16,800	0	0
2	474	5,200	110,100	125,500	15,400	15,400	0	0
2	475	7,400	107,900	124,000	16,100	16,100	0	0
4	470	0	115,300	115,300	0	-1,500	RANDOM	1,500
4	472	0	115,300	118,200	2,900	1,400	RANDOM	1,500
4	474	800	114,500	125,500	11,000	9,500	RANDOM	1,500
4	476	5,200	110,100	129,000	18,900	17,400	RANDOM	1,500
5	470	0	115,300	123,900	8,600	7,100	RANDOM	1,500
5	474	0	115,300	125,400	10,100	8,600	RANDOM	1,500
5	478	7,400	107,900	126,700	18,800	17,300	RANDOM	1,500
5	480	10,100	105,200	115,300	10,100	10,100	0	0
6	470	0	115,300	125,600	10,300	9,500	RANDOM	800
6	474	0	115,300	128,400	13,100	12,300	RANDOM	800
6	476	800	114,500	127,000	12,500	11,700	RANDOM	800
6	480	9,100	106,200	113,600	7,400	7,400	0	0
7	470	0	115,300	131,200	15,900	15,100	RANDOM	800
7	473	0	115,300	131,200	15,900	15,100	RANDOM	800
7	476	2,900	112,400	131,200	18,800	17,300	RANDOM	1,500
7	479	5,200	110,100	131,300	21,200	19,700	RANDOM	1,500
7	481	9,100	106,200	131,300	25,100	24,300	RANDOM	800
8	470	0	115,300	131,300	16,000	14,500	RANDOM	1,500
8	473	0	115,300	136,400	21,100	19,600	RANDOM	1,500
8	479	2,900	112,400	133,200	20,800	20,000	RANDOM	800
8	482	9,100	106,200	131,300	25,100	25,100	0	0
9	470	0	115,300	132,000	16,700	15,200	RANDOM	1,500
9	472	0	115,300	131,500	16,200	14,700	RANDOM	1,500
9	480	2,900	112,400	133,400	21,000	20,200	RANDOM	800
9	483	9,100	107,900	103,500	-4,400	-4,400	0	0

(Continued)

Note: See Plates 42 and 43 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Table 6 (Concluded)

G_o ft	TW EL	F_2 lb	F_3 lb	F_4 lb	F_{5max} lb	F_{5min} lb	f Hz	Δ_p lb
10	470	0	115,300	132,100	16,800	15,300	RANDOM	1,500
10	472	0	115,300	131,400	16,100	15,300	RANDOM	800
10	478	0	115,300	126,000	10,700	10,700	0	0
10	483	7,400	107,900	123,000	15,100	15,100	0	0

Table 7

Gate Cable Loads and Vibrations

Type 3 Design Structure

Flow Over Gate

Gate Submergence ft	TW EL	F_2 lb	F_3 lb	F_4 lb	F_{5max} lb	F_{5min} lb	f Hz	Δ_p lb
1	470	2,900	112,400	137,100	24,700	24,700	0	0
1	471	5,200	110,100	132,800	22,700	22,700	0	0
2	470	5,200	110,100	128,400	18,300	17,500	RANDOM	800
2	472	9,100	106,200	131,300	25,100	25,100	0	0
2	473	10,100	105,200	128,400	23,200	23,200	0	0
2	475	11,300	104,000	115,200	11,200	11,200	0	0
3	470	7,400	107,900	123,900	16,000	16,000	0	0
3	472	10,100	105,200	121,000	15,800	15,800	0	0
3	474	11,300	104,000	113,700	9,700	9,700	0	0
3	476	12,450	102,850	112,850	10,000	10,000	0	0
4	470	9,100	106,200	156,100	49,900	49,900	0	0
4	472	10,700	104,600	148,800	44,200	44,200	0	0
4	474	11,850	103,450	144,400	40,950	40,950	0	0
4	476	13,000	102,300	138,500	36,200	36,200	0	0
5	470	10,100	105,200	141,500	36,300	36,300	0	0
5	472	11,300	104,000	132,700	28,700	27,200	RANDOM	1,500
5	475	13,000	102,300	122,500	20,200	20,200	0	0
5	478	14,800	100,500	120,000	19,500	19,500	0	0
6	470	10,700	104,600	126,900	22,300	21,500	RANDOM	800
6	472	11,850	103,450	118,100	14,650	14,650	0	0
6	476	14,200	101,100	107,900	6,800	6,800	0	0
7	470	11,300	104,000	116,100	12,100	12,900	RANDOM	800
7	472	12,450	102,850	118,250	15,400	15,400	0	0
7	476	14,800	100,500	83,000	-17,500	-17,500	0	0
7	477	15,300	100,000	78,700	-21,300	-21,300	0	0
8	470	11,850	103,450	150,400	46,950	46,950	0	0
8	473	13,600	101,700	138,600	36,900	36,900	0	0
8	478	15,300	100,000	131,000	31,000	31,000	0	0
8	483	15,300	100,000	61,300	-38,700	-38,700	0	0

Note: See Plates 42 and 43 for definitions of symbols. Dry weight of gate F_1 = 115,300 lb.

Photo 1. Flow under the gate, gate open 7 ft, headwater el 483.17, tailwater el 470.00

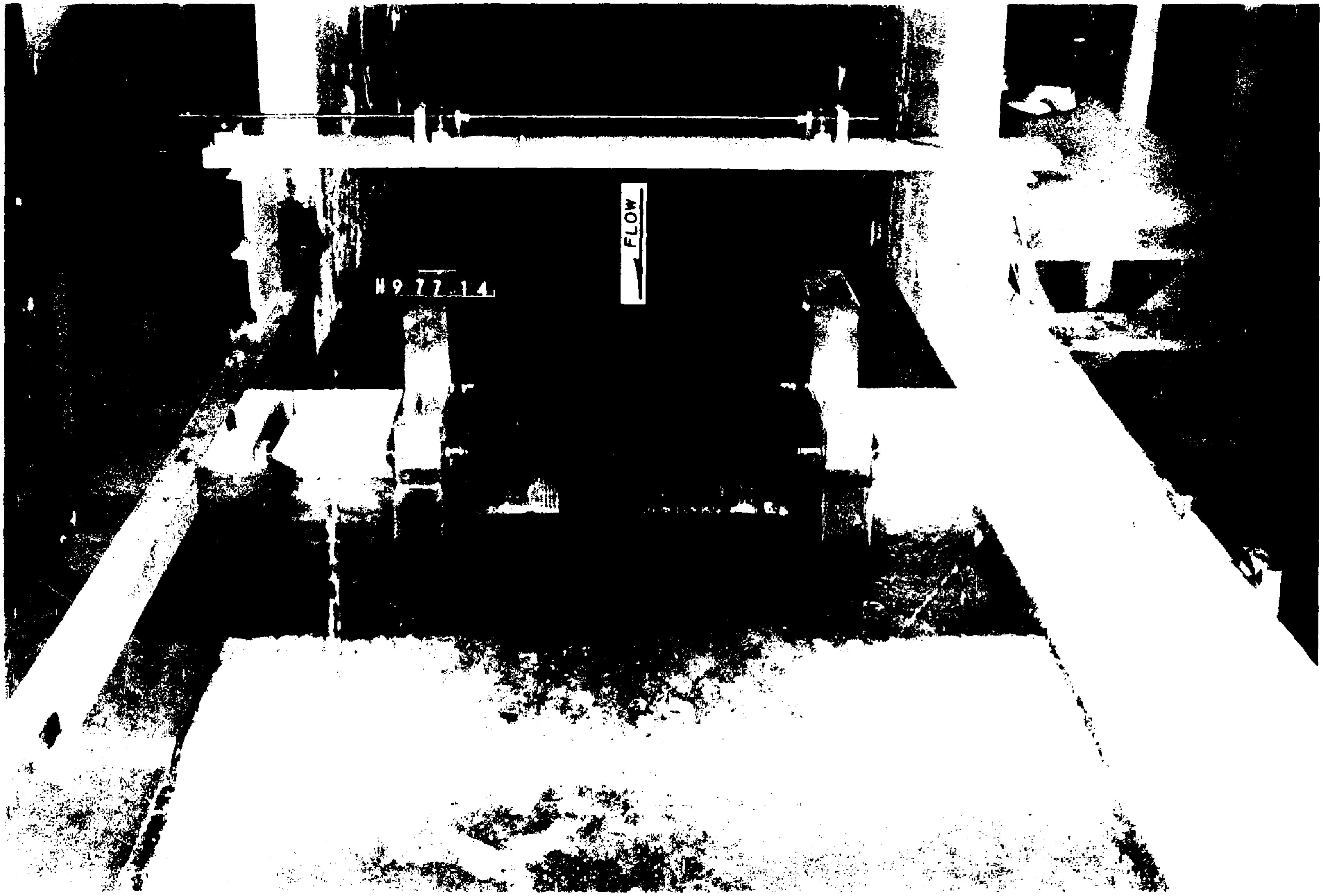


Photo 2. Flow over the gate, gate submerged 8 ft, headwater el 483.17, tailwater el 470.00

Photo 3. Gate open 3 ft, headwater el 483.17, tailwater el 476.00

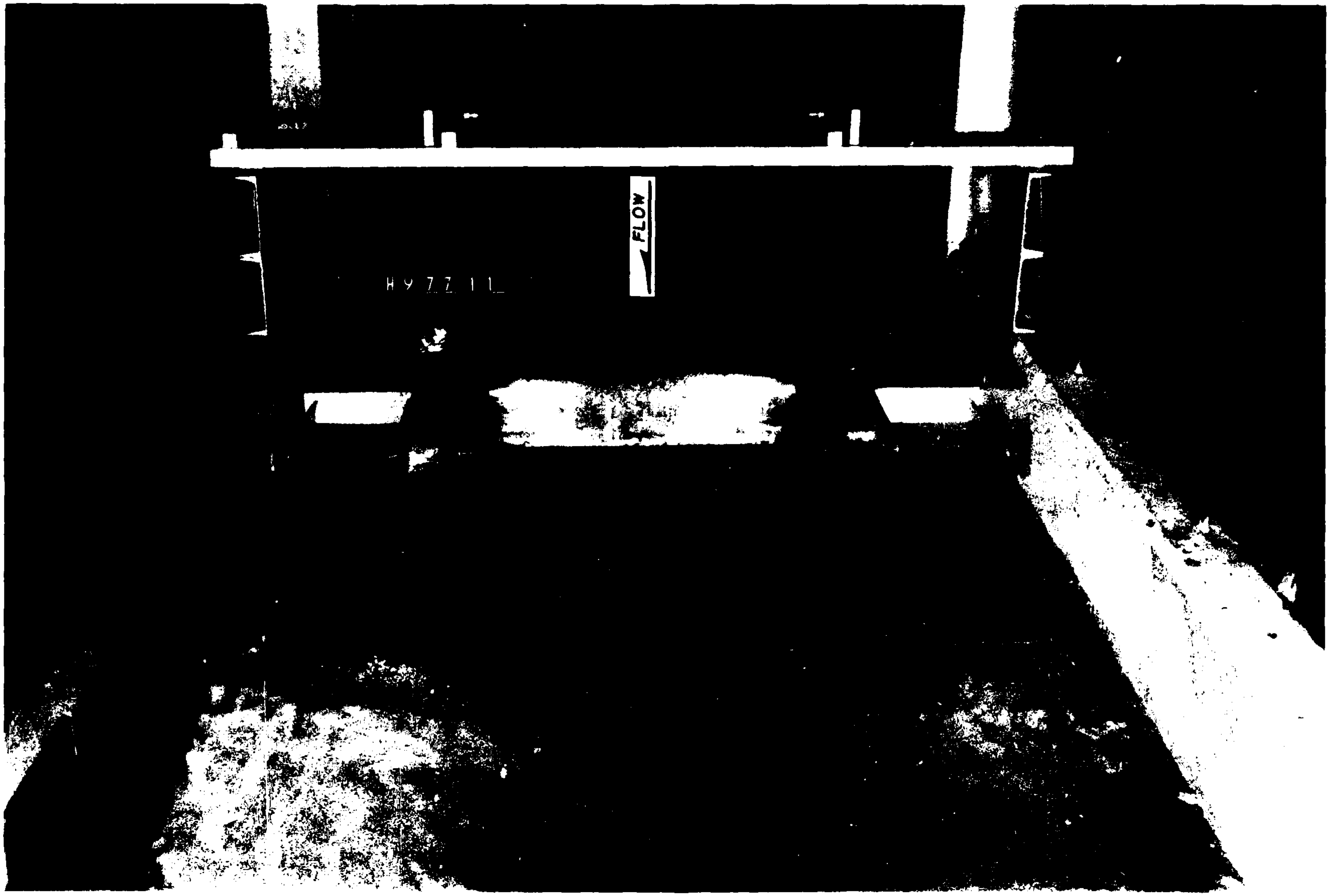


Photo 4. Gate open 4 ft, headwater el 483.17, tailwater el 474.00

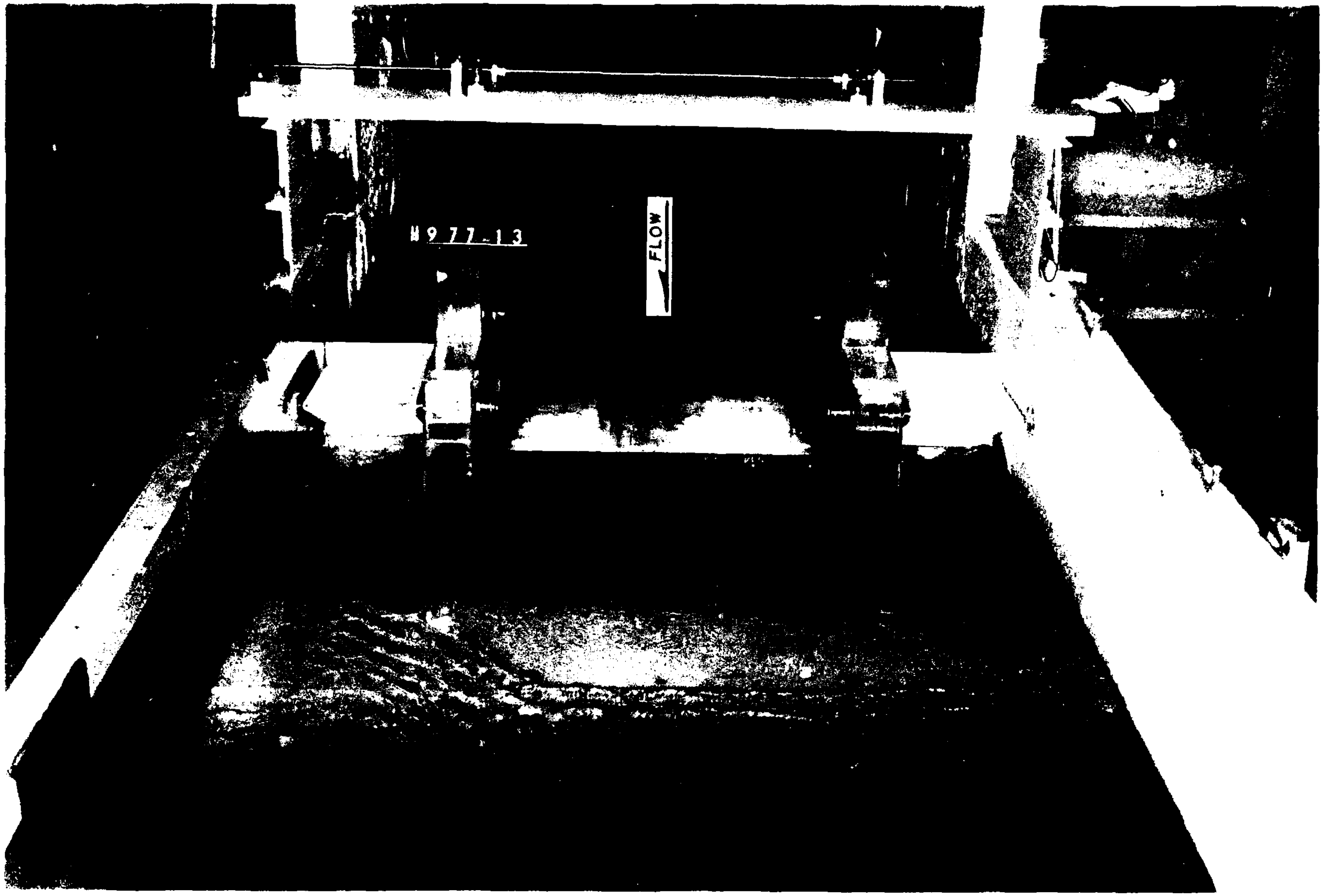
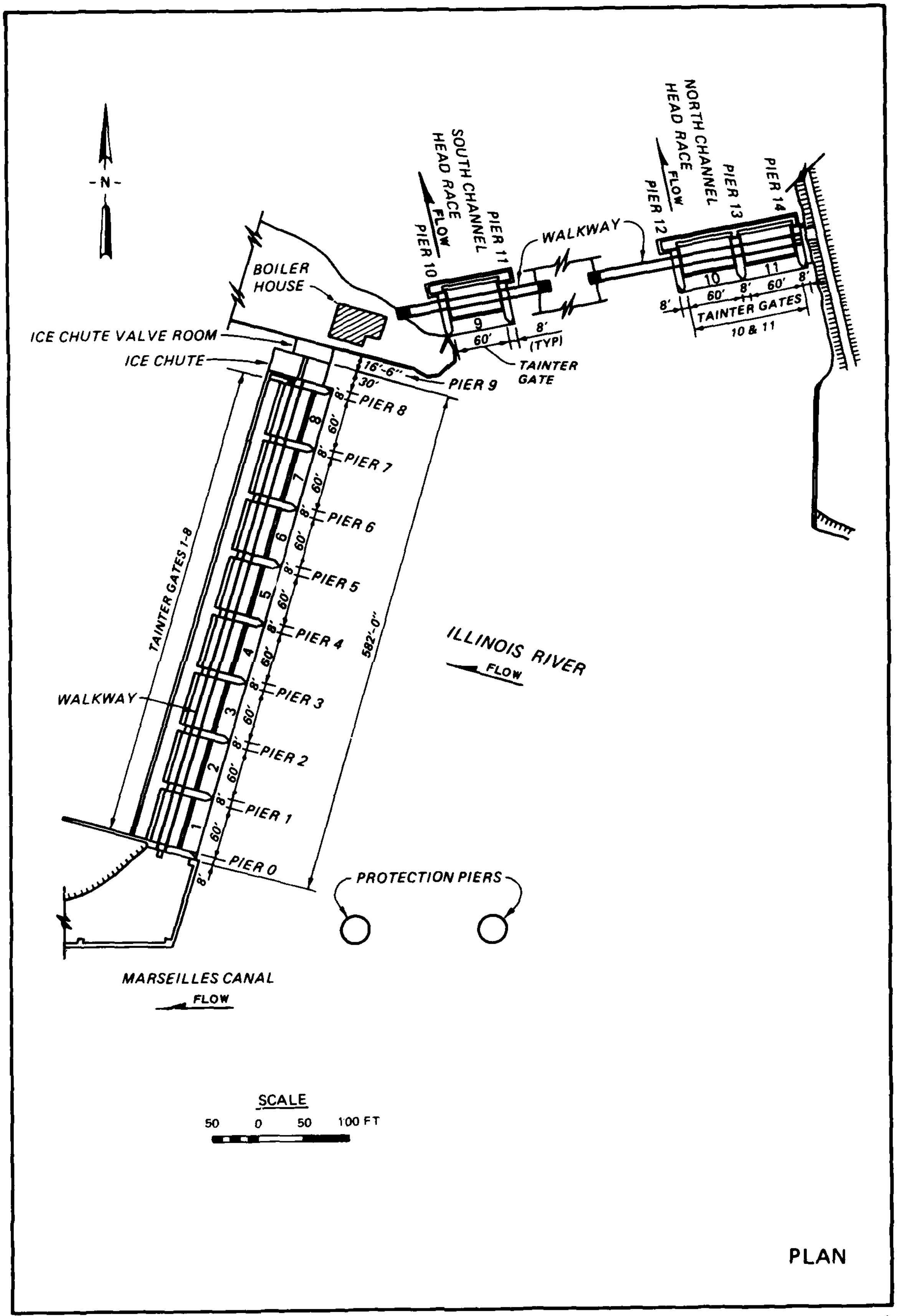
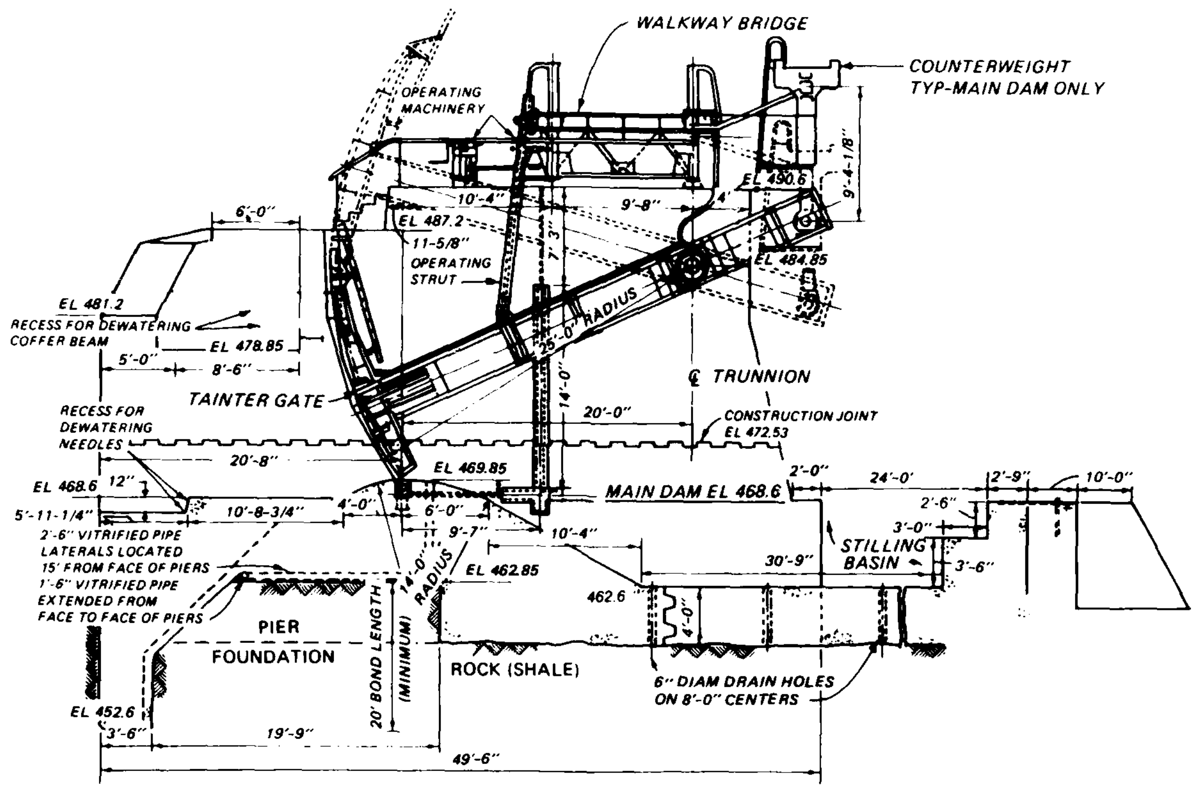


Photo 5. Gate submerged 2 ft, headwater el 483.17, tailwater el 470.00

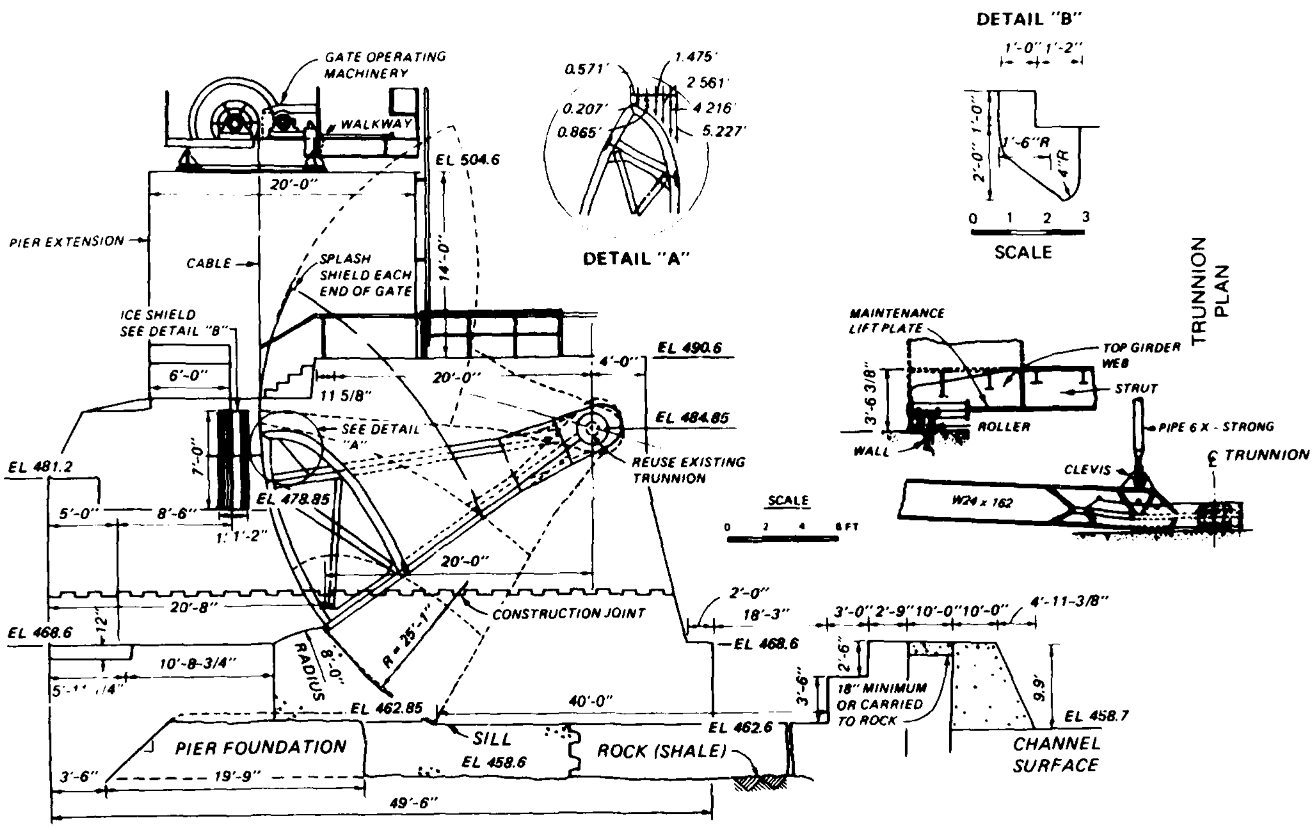

N
BOILER HOUSE
ICE CHUTE VALVE ROOM
ICE CHUTE
SOUTH CHANNEL HEAD RACE
FLOW
PIER 10
PIER 11
WALKWAY
NORTH CHANNEL HEAD RACE
FLOW
PIER 12
PIER 13
PIER 14
9
60'
8' (TYP)
TAINTER GATE
10
11
60'
8'
8'
60'
TAINTER GATES 10 & 11
16'-6"
30'
PIER 9
PIER 8
PIER 7
PIER 6
PIER 5
PIER 4
PIER 3
PIER 2
PIER 1
PIER 0
TAINTER GATES 1-8
582'-0"
WALKWAY
ILLINOIS RIVER
FLOW
PROTECTION PIERS
MARSEILLES CANAL
FLOW
SCALE
50 0 50 100 FT
PLAN



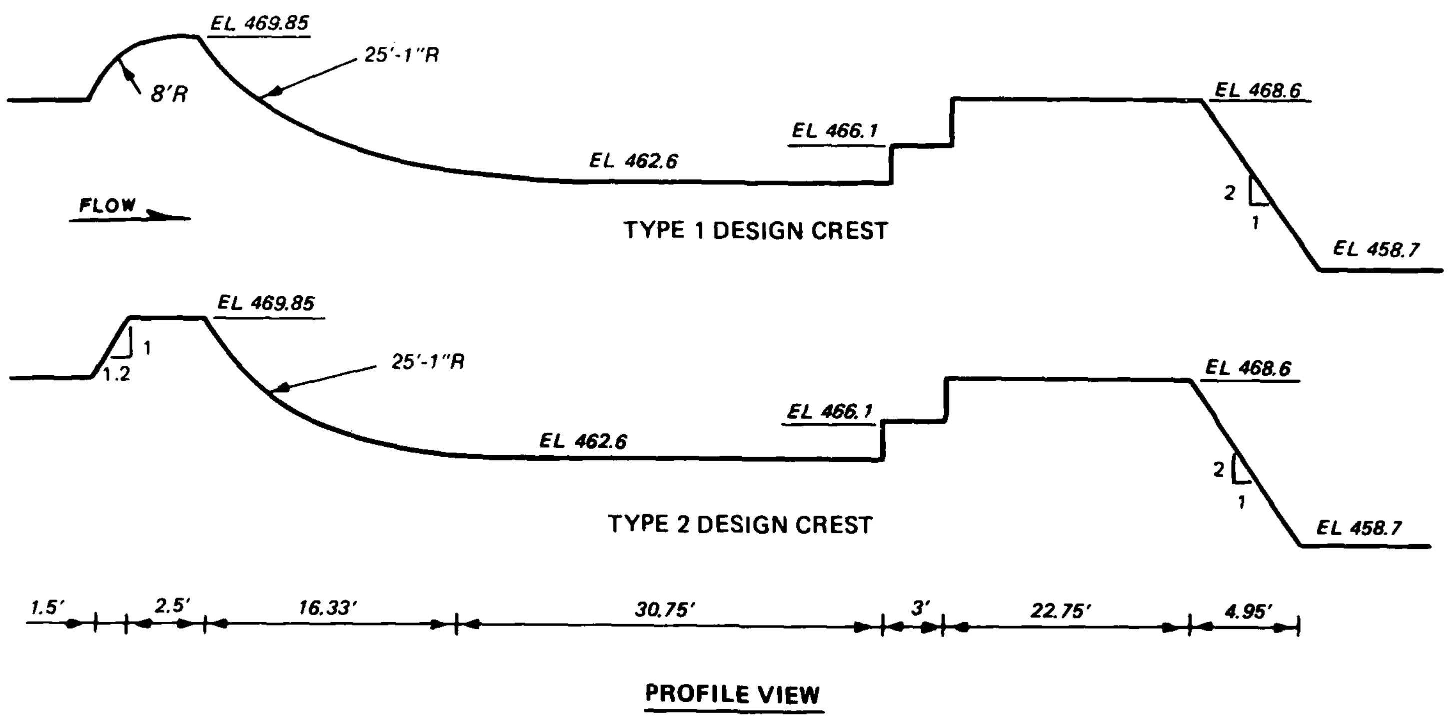
NOTE: EXISTING CONDITIONS AT THE TIME THE MODEL STUDY WAS CONDUCTED

EXISTING NONSUBMERSIBLE TAINTER GATE AND PIER PROFILE

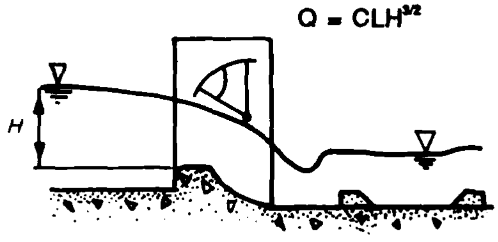
PLATE 2



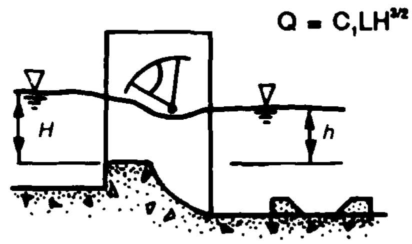
DETAILS OF SPILLWAY SUBMERSIBLE - TYPE TAINTER GATE
TYPE 1 (ORIGINAL) DESIGN STRUCTURE



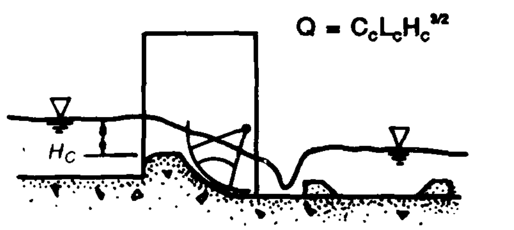
TYPES 1 AND 2 DESIGN SPILLWAY CRESTS AND STILLING BASIN



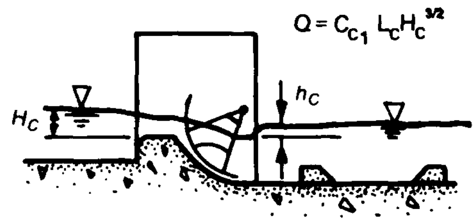
FREE UNCONTROLLED FLOW



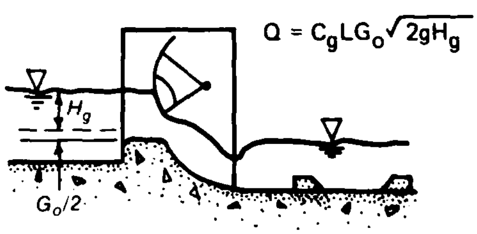
SUBMERGED UNCONTROLLED FLOW



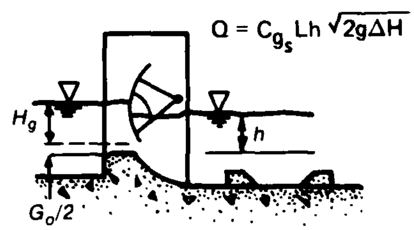
FREE UNCONTROLLED FLOW
(OVER THE GATE)*



SUBMERGED UNCONTROLLED FLOW
(OVER THE GATE)*



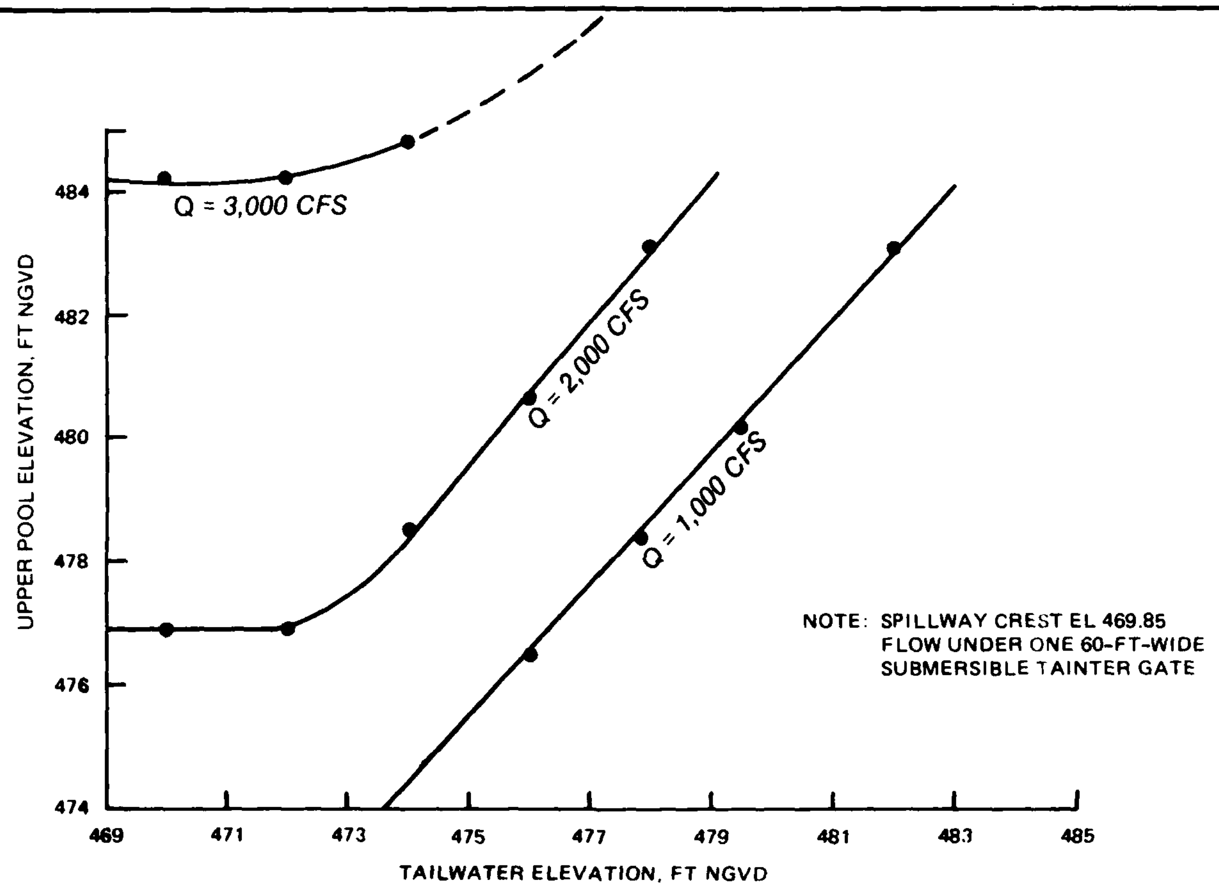
FREE CONTROLLED FLOW



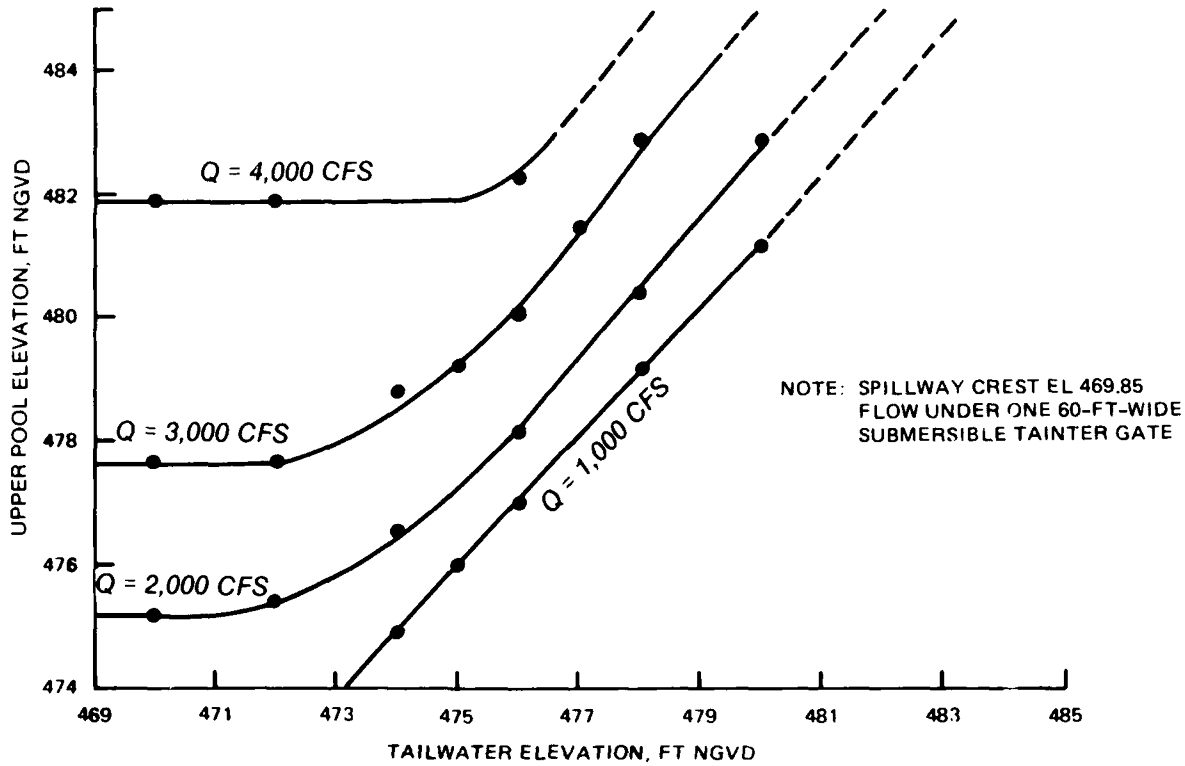
SUBMERGED CONTROLLED FLOW

* NOTE. FLOW OVER GATE IS UNCONTROLLED FLOW BECAUSE GATE ACTS AS AN OGEE WEIR FIXED AT SEVERAL ELEVATIONS.

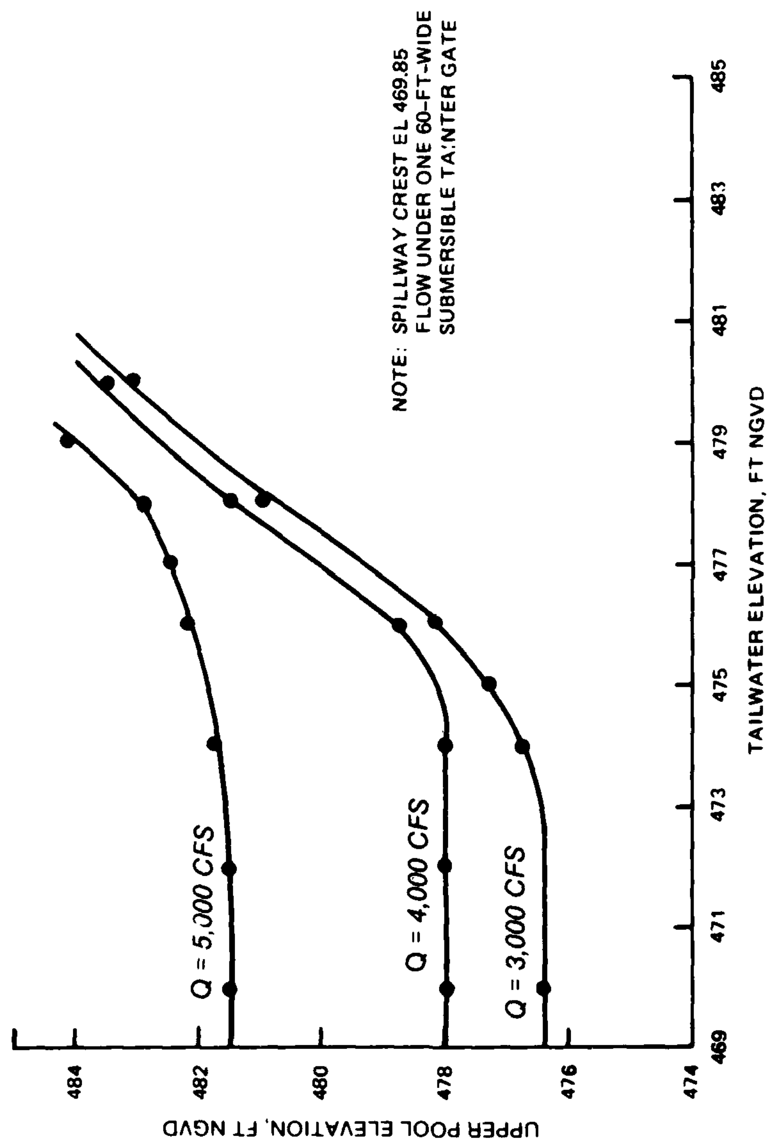
SIX FLOW REGIMES



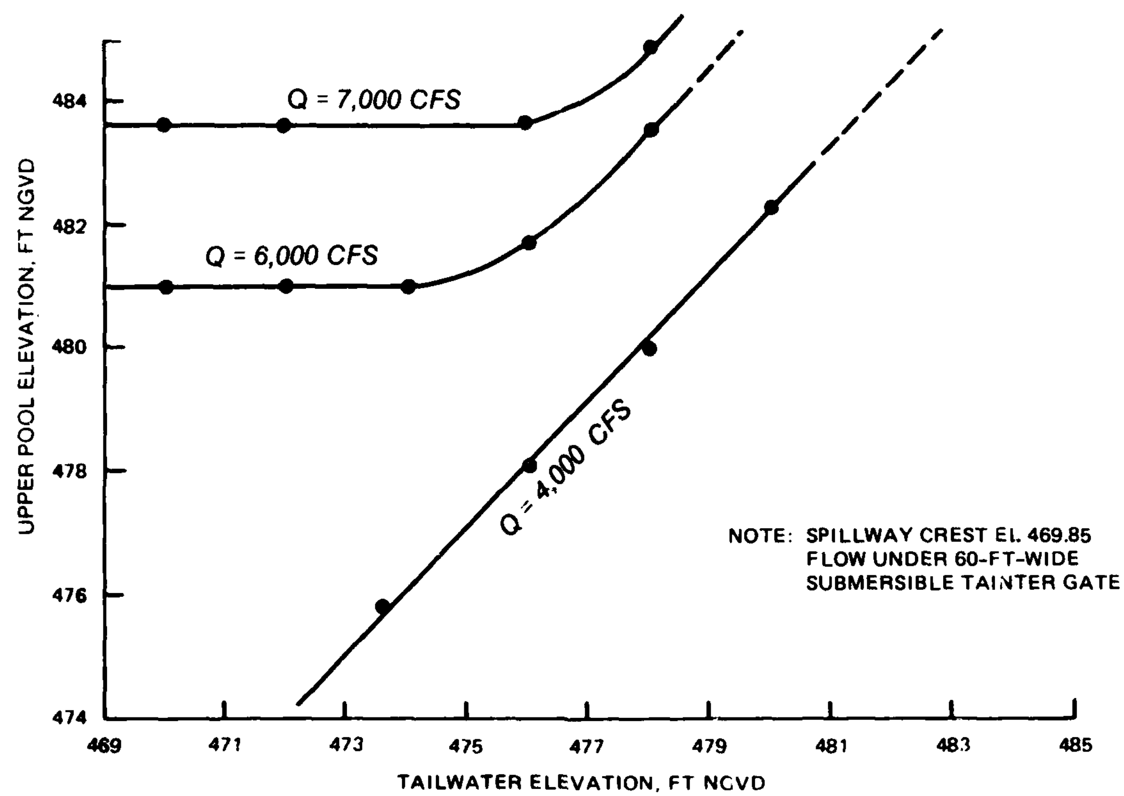
CALIBRATION DATA
CONTROLLED FLOW
2-FT GATE OPENING
TYPE 1 SPILLWAY CREST



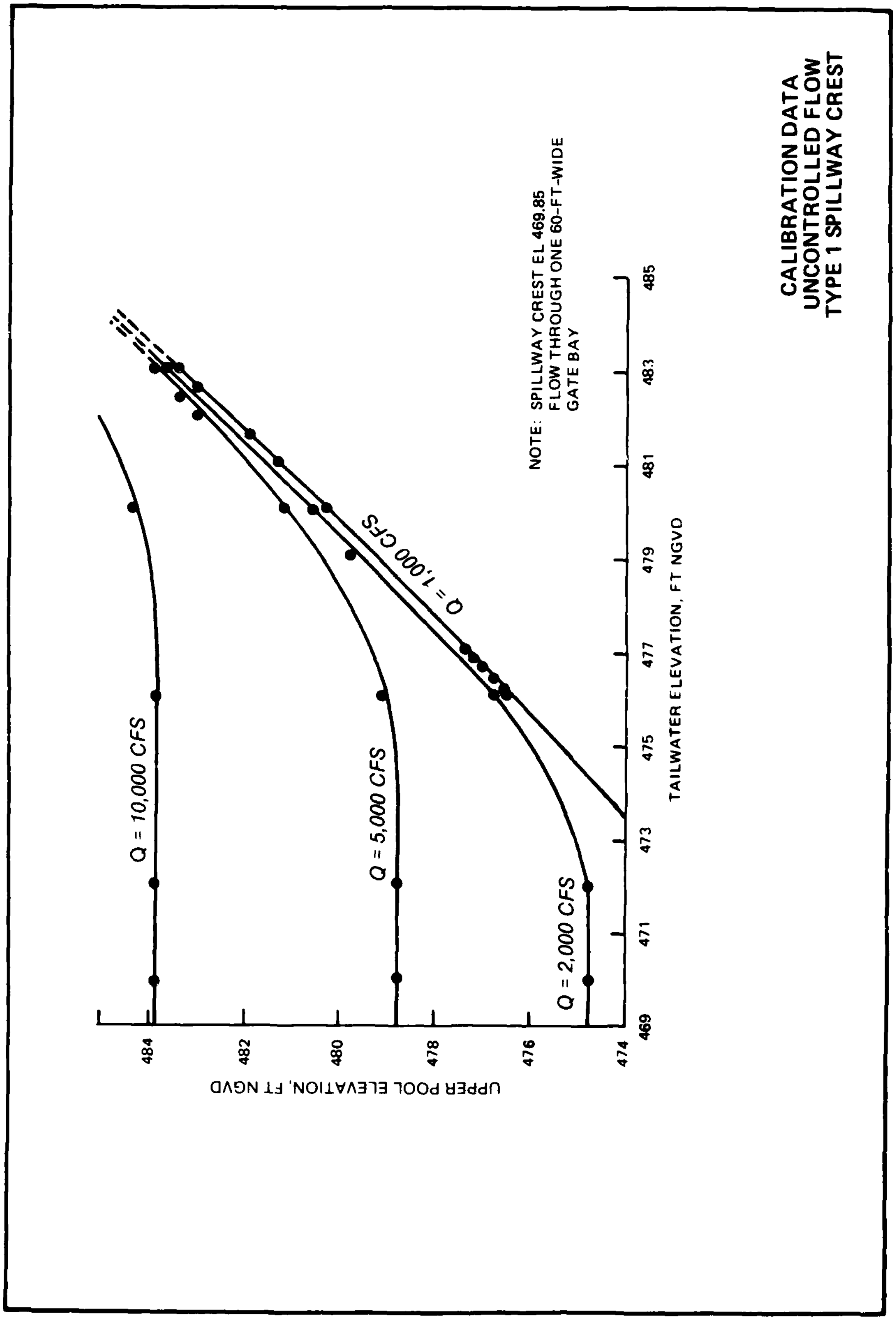
**CALIBRATION DATA
CONTROLLED FLOW
4-FT GATE OPENING
TYPE 1 SPILLWAY CREST**

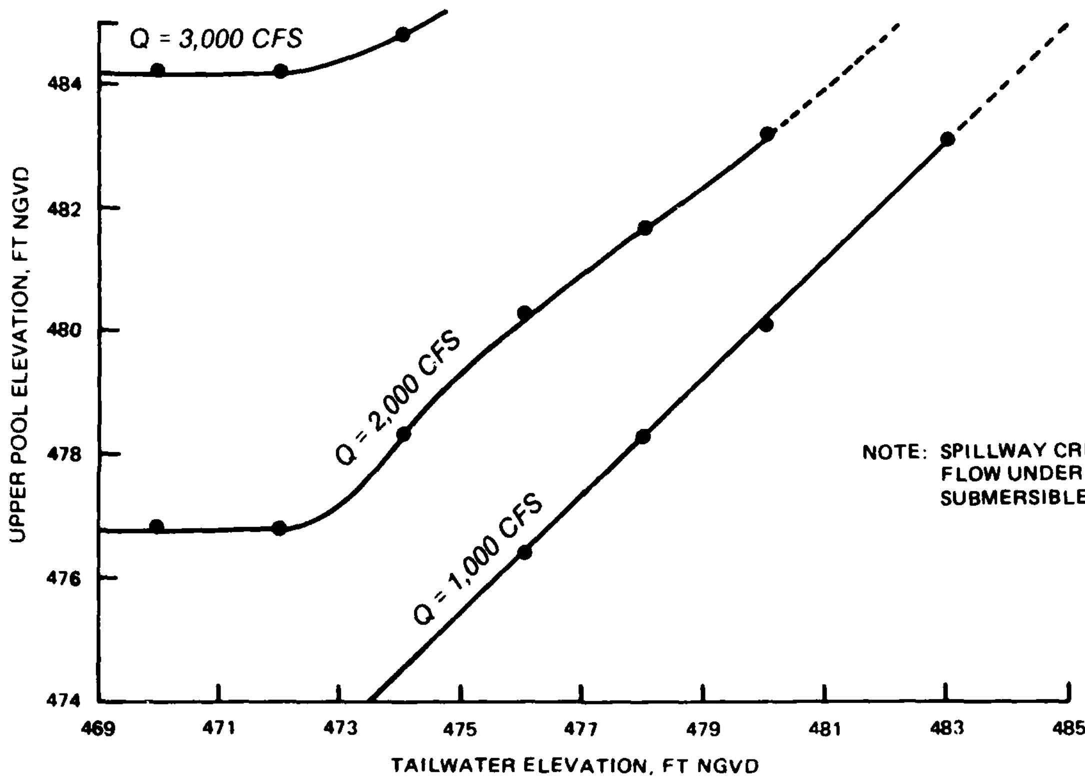


CALIBRATION DATA
CONTROLLED FLOW
6-FT GATE OPENING
TYPE 1 SPILLWAY CREST



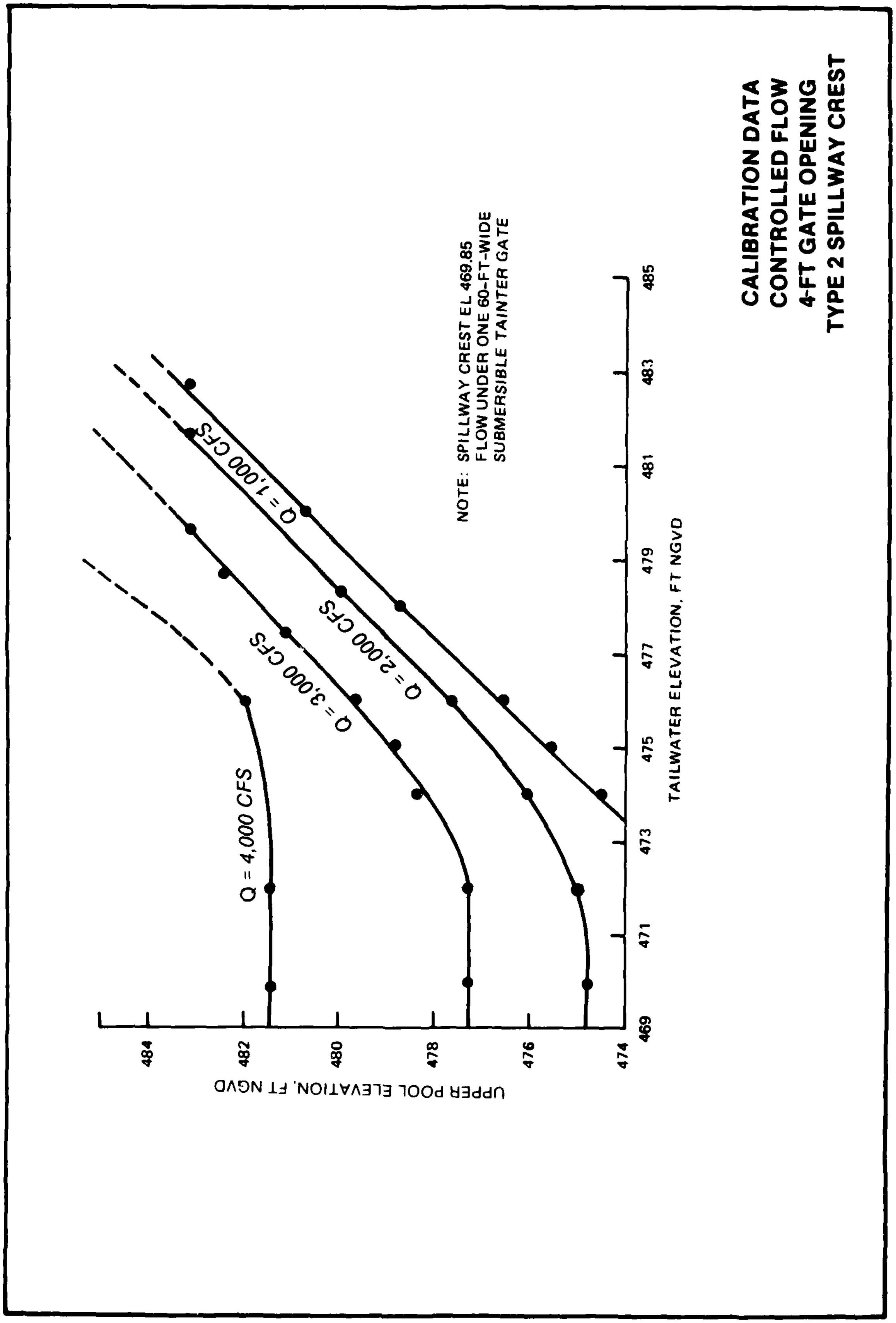
CALIBRATION DATA
CONTROLLED FLOW
8-FT GATE OPENING
TYPE 1 SPILLWAY CREST

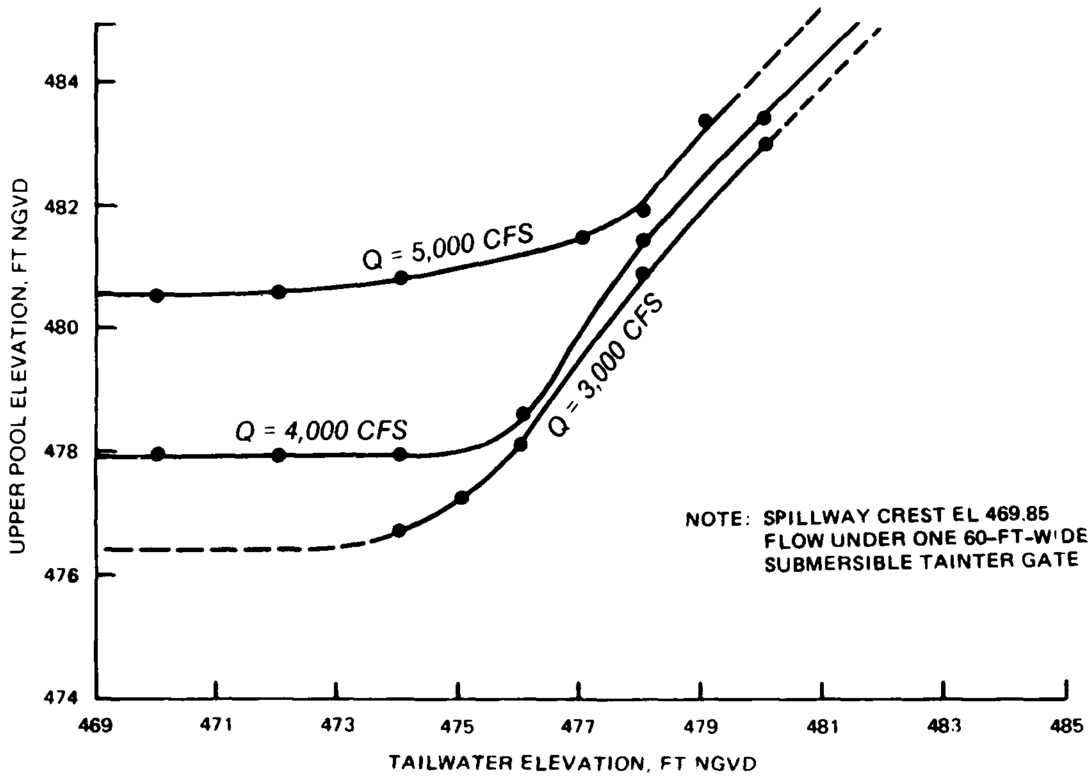

CALIBRATION DATA
UNCONTROLLED FLOW
TYPE 1 SPILLWAY CREST
NOTE: SPILLWAY CREST EL 469.85
FLOW THROUGH ONE 60-FT-WIDE
GATE BAY
Q = 10,000 CFS
Q = 5,000 CFS
Q = 2,000 CFS
Q = 1,000 CFS
UPPER POOL ELEVATION, FT NGVD
TAILWATER ELEVATION, FT NGVD
474
476
478
480
482
484
469
471
473
475
477
479
481
483
485



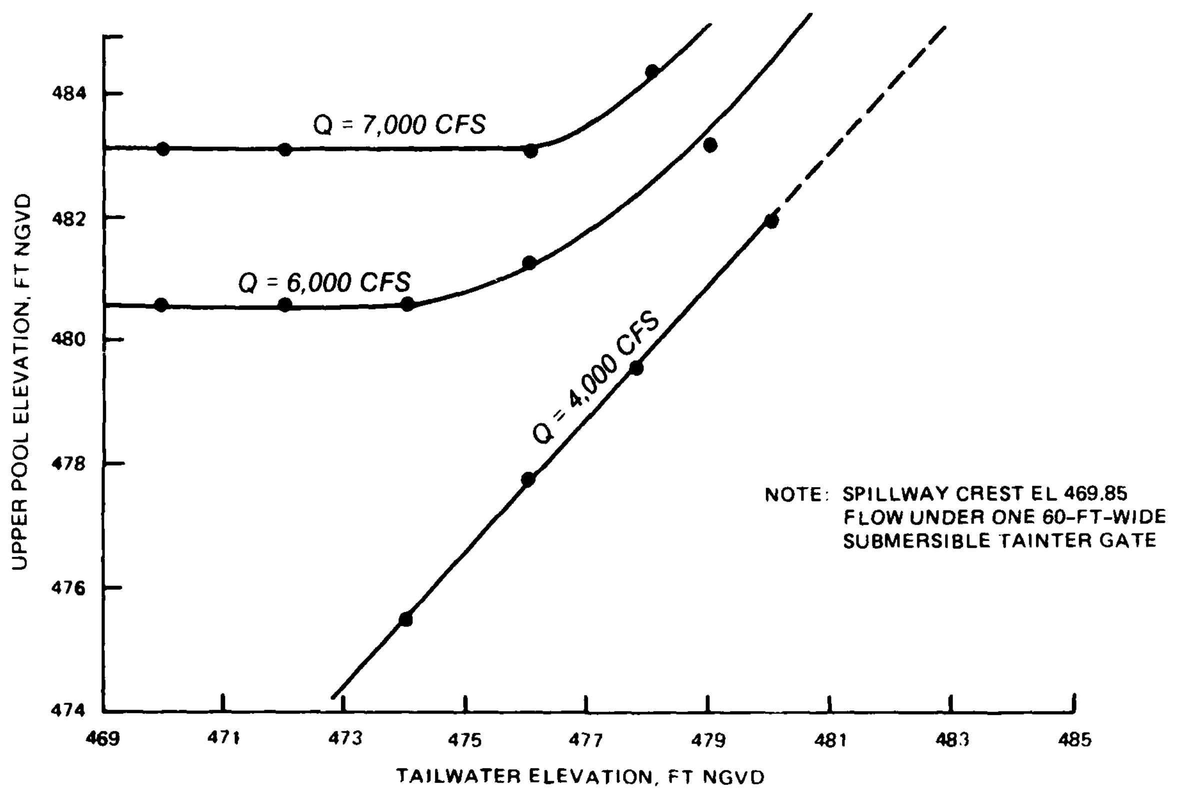
NOTE: SPILLWAY CREST EL 469.85
FLOW UNDER ONE 60-FT-WIDE
SUBMERSIBLE TAINTER GATE

**CALIBRATION DATA
CONTROLLED FLOW
2-FT GATE OPENING
TYPE 2 SPILLWAY CREST**

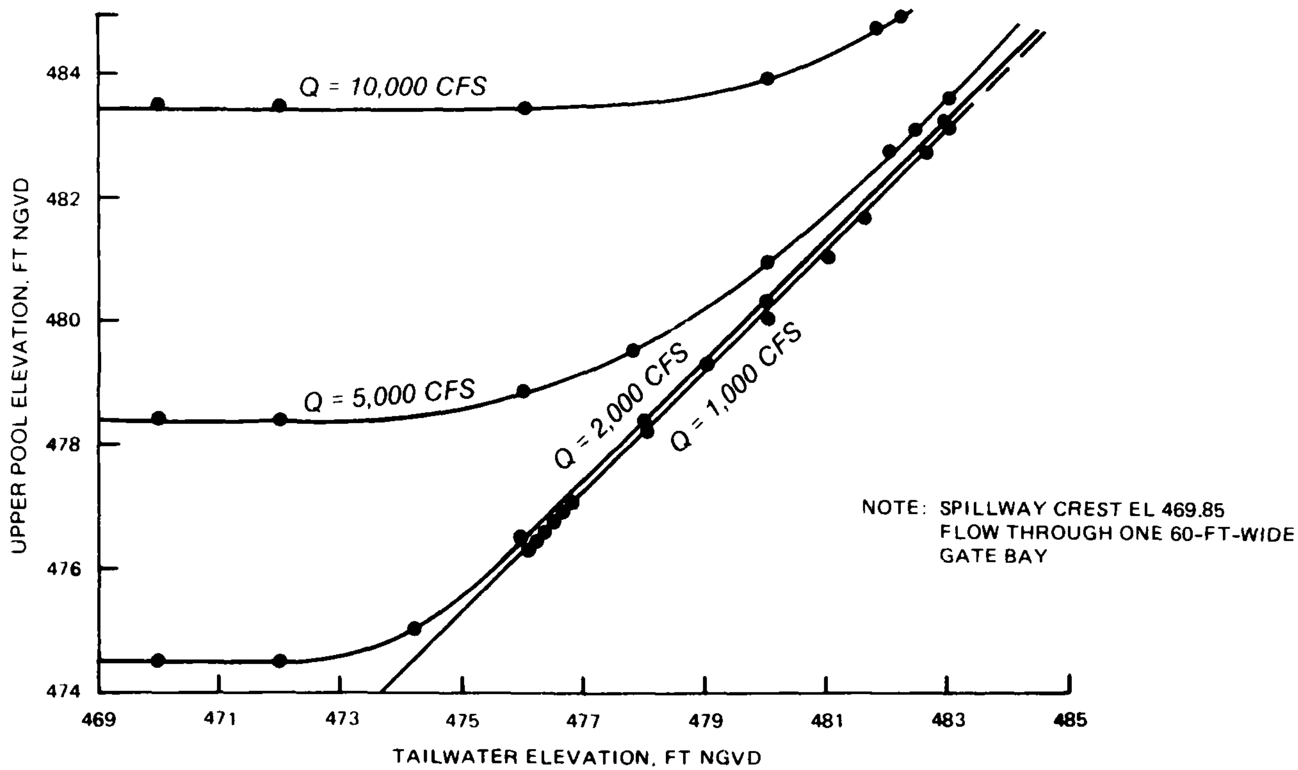

CALIBRATION DATA
CONTROLLED FLOW
4-FT GATE OPENING
TYPE 2 SPILLWAY CREST
NOTE: SPILLWAY CREST EL 469.85
FLOW UNDER ONE 60-FT-WIDE
SUBMERSIBLE TAINTER GATE
Q = 1,000 CFS
Q = 2,000 CFS
Q = 3,000 CFS
Q = 4,000 CFS
UPPER POOL ELEVATION, FT NGVD
TAILWATER ELEVATION, FT NGVD
474
476
478
480
482
484
469
471
473
475
477
479
481
483
485



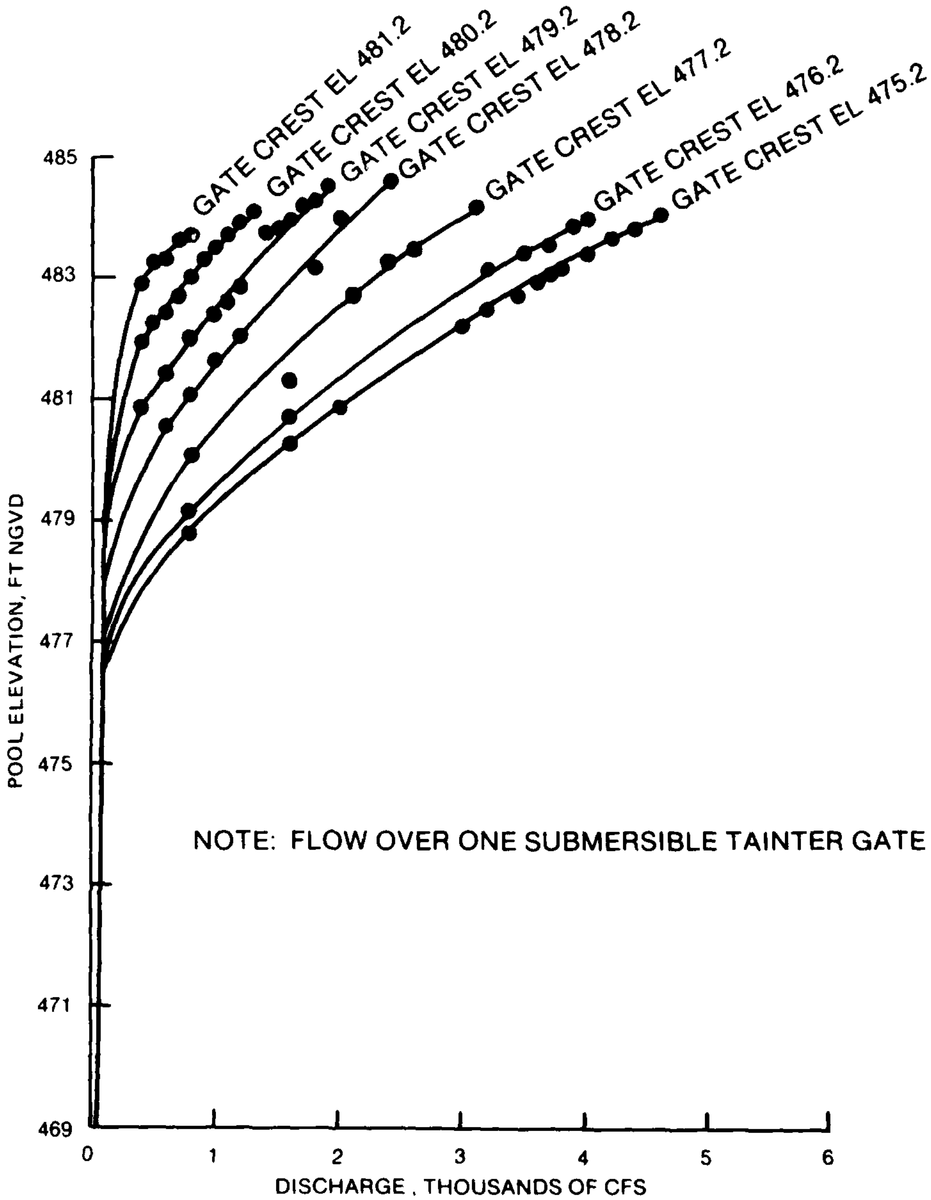
CALIBRATION DATA
CONTROLLED FLOW
6-FT GATE OPENING
TYPE 2 SPILLWAY CREST



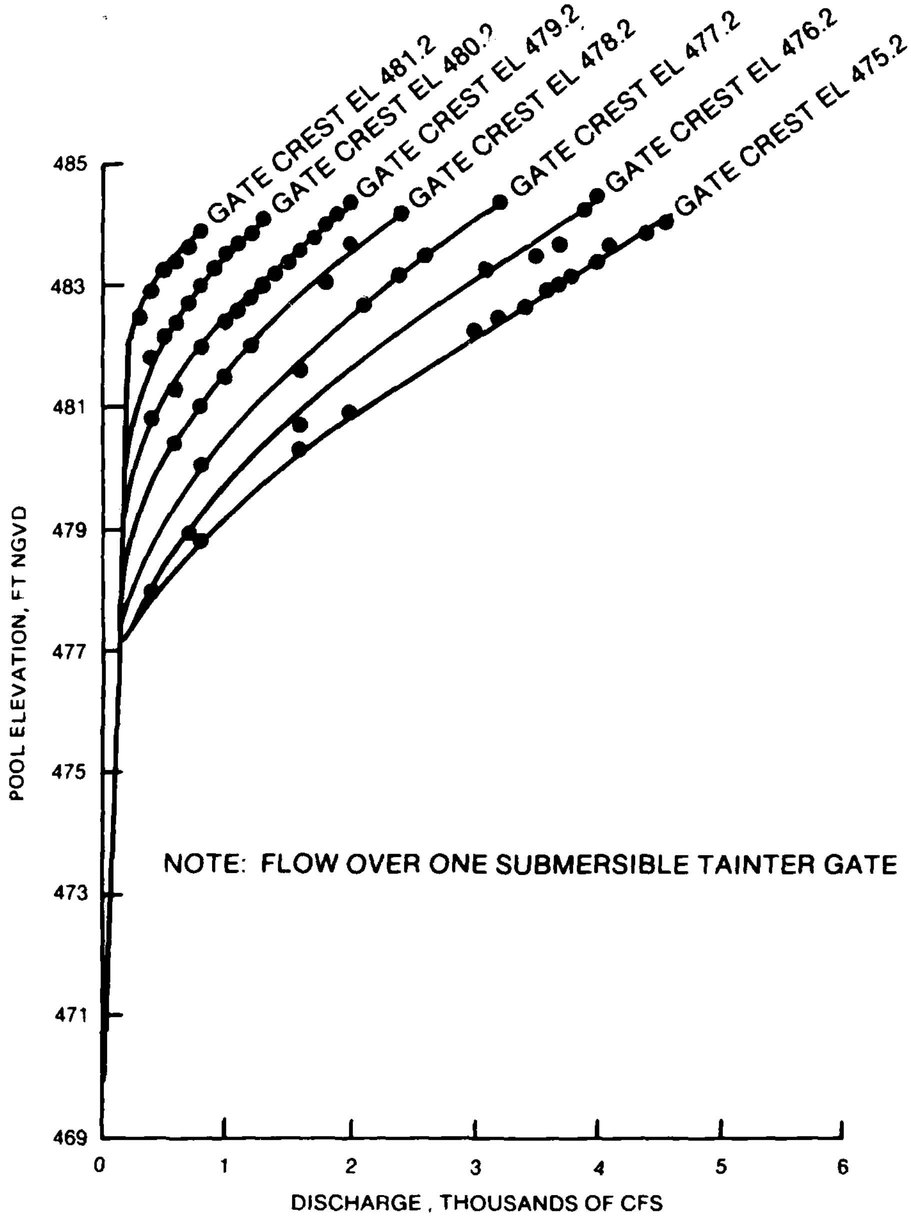
**CALIBRATION DATA
CONTROLLED FLOW
8-FT GATE OPENING
TYPE 2 SPILLWAY CREST**



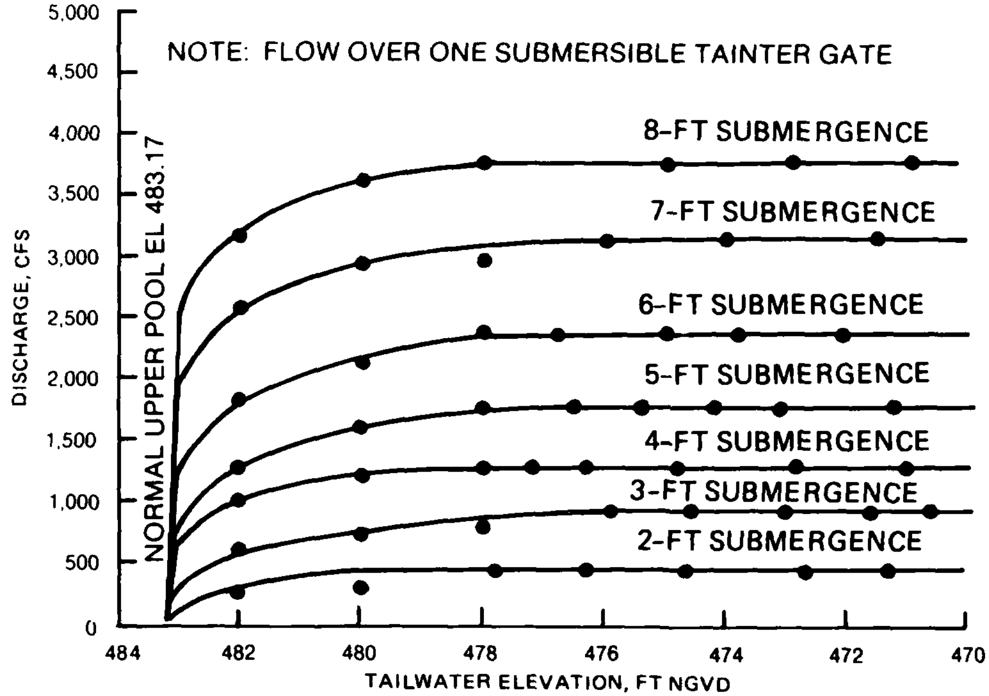
CALIBRATION DATA
UNCONTROLLED FLOW
TYPE 2 SPILLWAY CREST



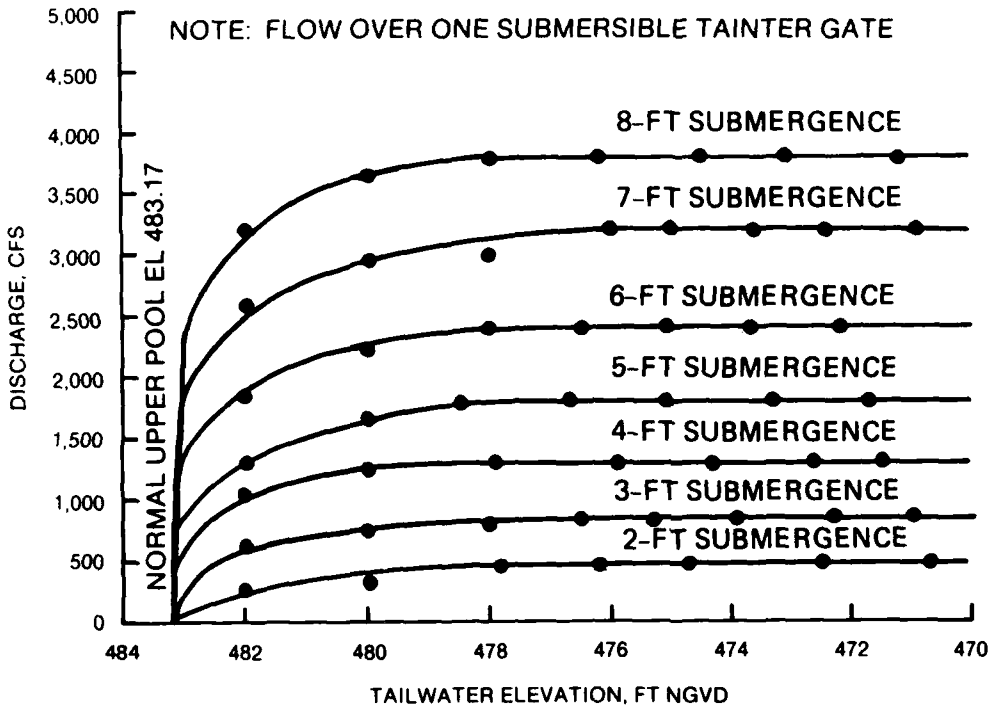
DISCHARGE RATING CURVE
FOR FREE FLOW
OVER GATE
TYPE 1 SPILLWAY CREST



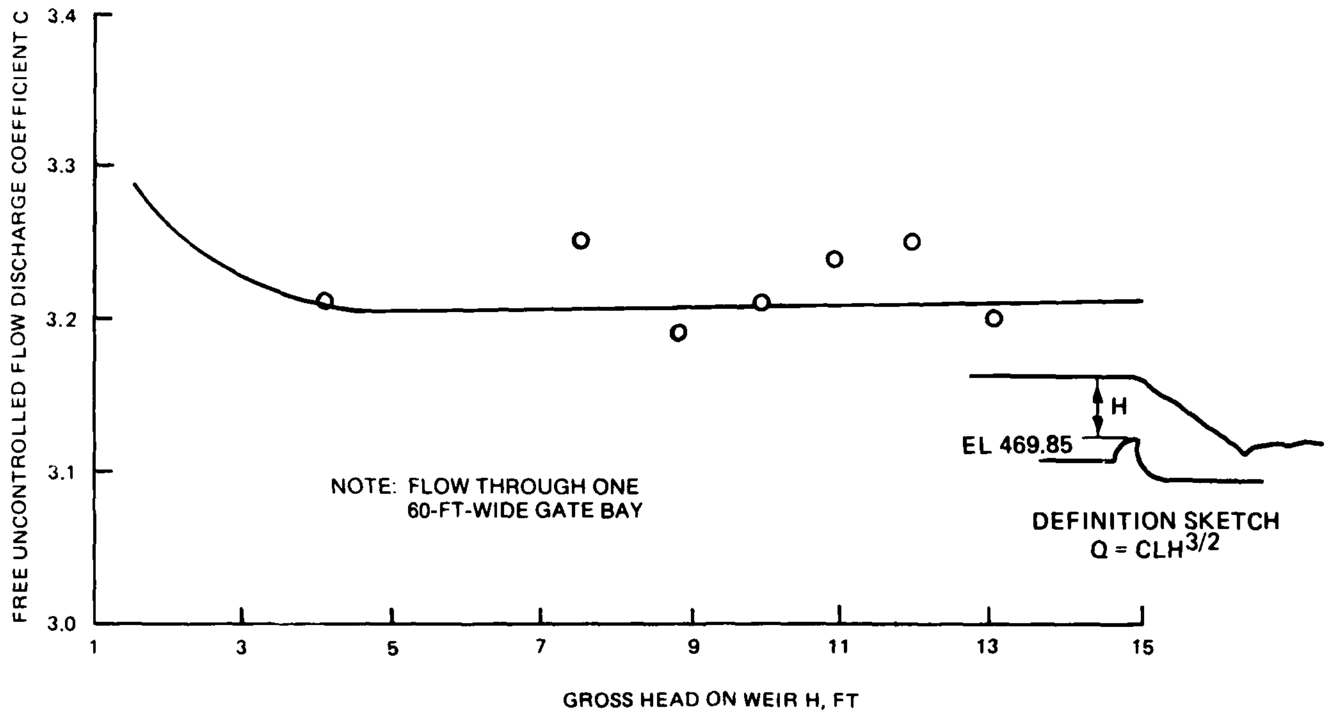
DISCHARGE RATING CURVE
FOR FREE FLOW
OVER GATE
TYPE 2 SPILLWAY CREST



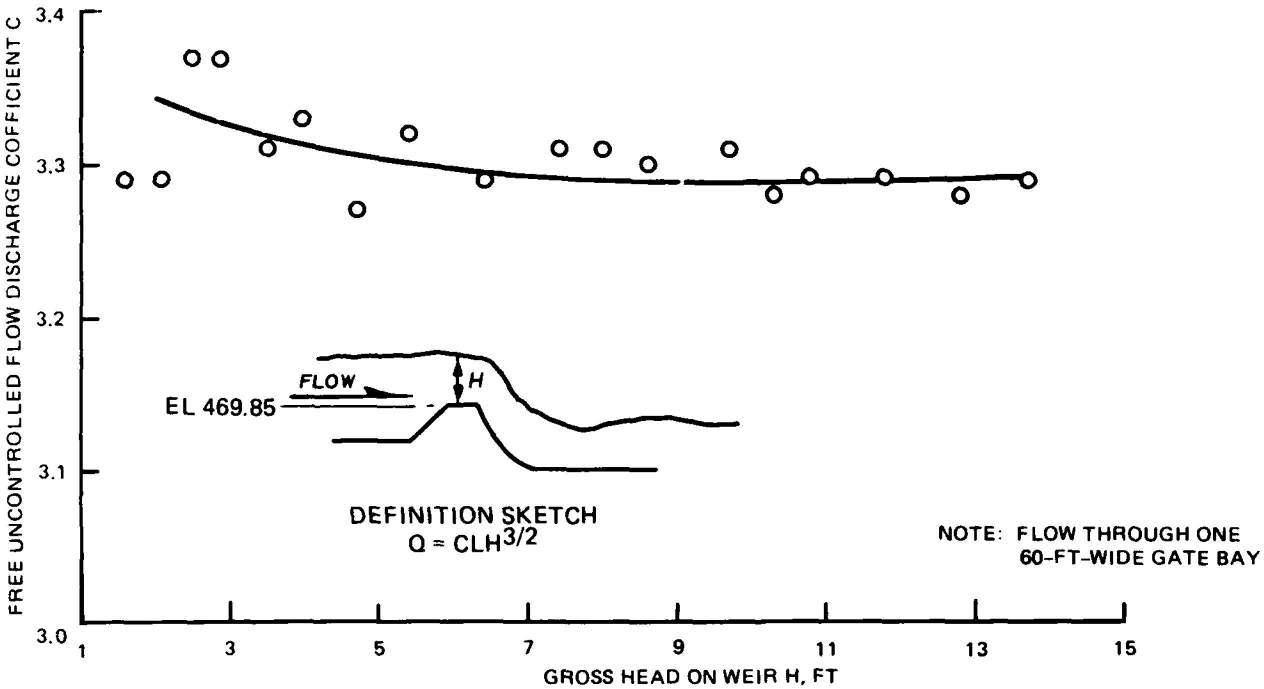
EFFECT OF TAILWATER ELEVATION ON DISCHARGE FLOW OVER GATE TYPE 1 SPILLWAY CREST



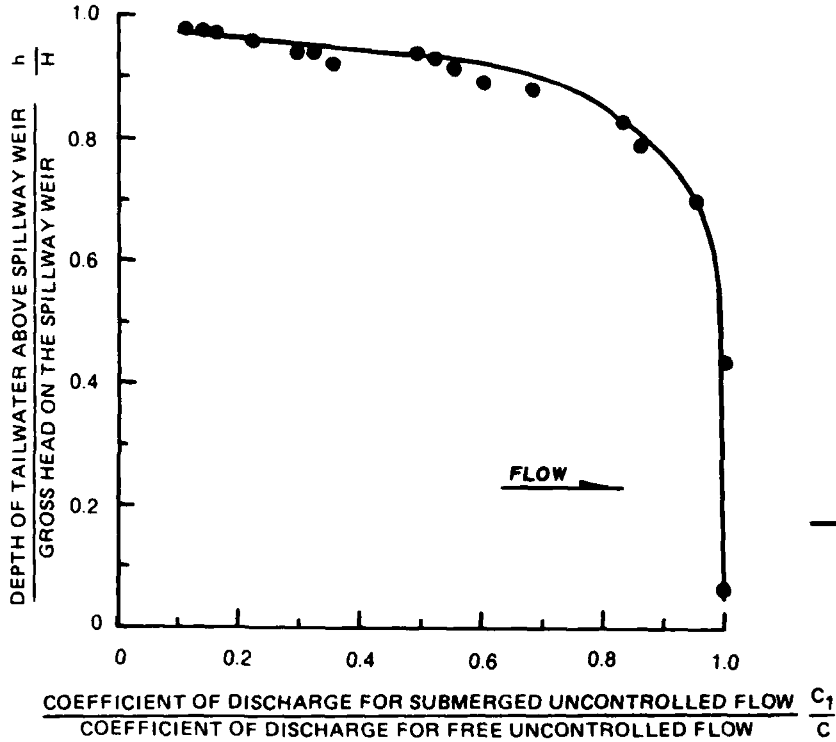
EFFECT OF TAILWATER ELEVATION ON DISCHARGE FLOW OVER GATE TYPE 2 SPILLWAY CREST

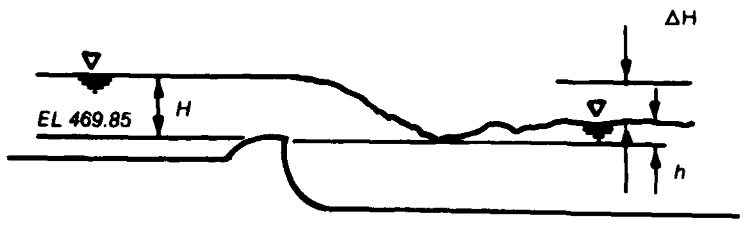


**DISCHARGE COEFFICIENTS
FOR FREE UNCONTROLLED FLOW
TYPE 1 SPILLWAY CREST**



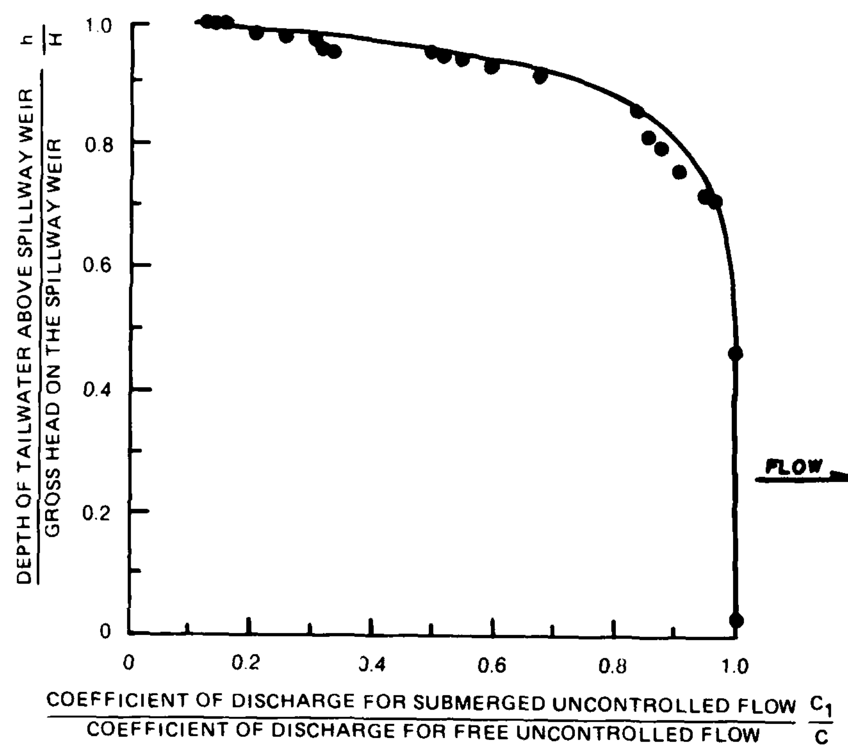
DISCHARGE COFFICIENTS
FOR FREE UNCONTROLLED FLOW
TYPE 2 SPILLWAY CREST

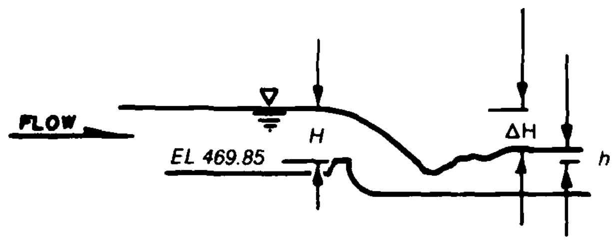




DEFINITION SKETCH

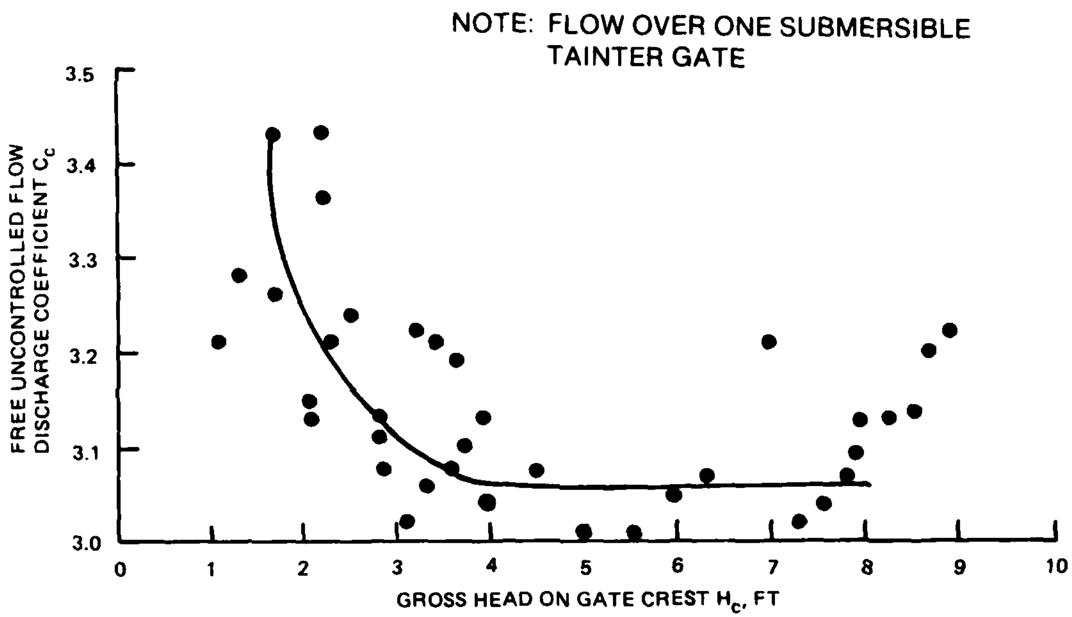
DISCHARGE COEFFICIENTS
FOR SUBMERGED UNCONTROLLED FLOW
TYPE 1 SPILLWAY CREST



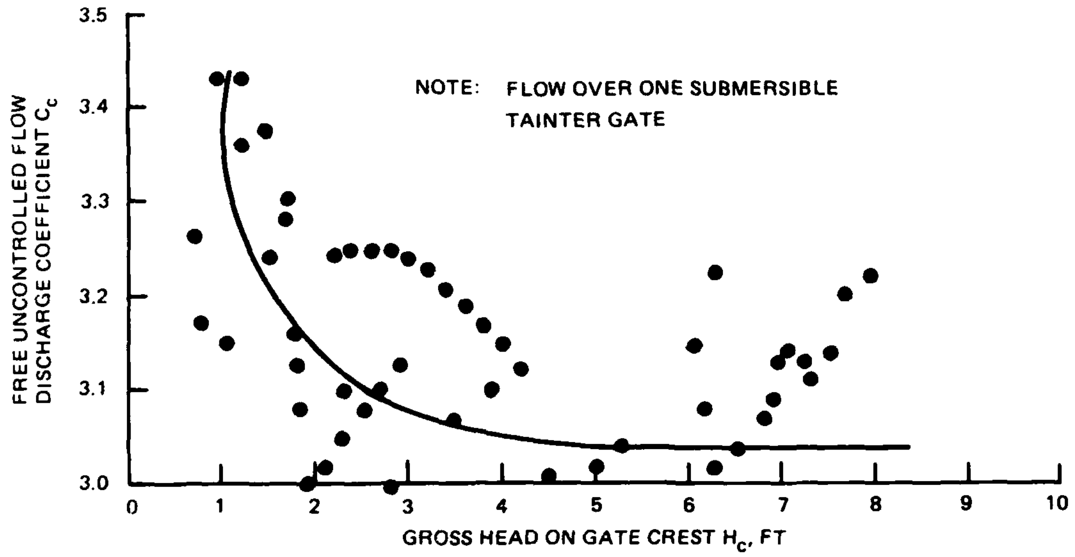


DEFINITION SKETCH

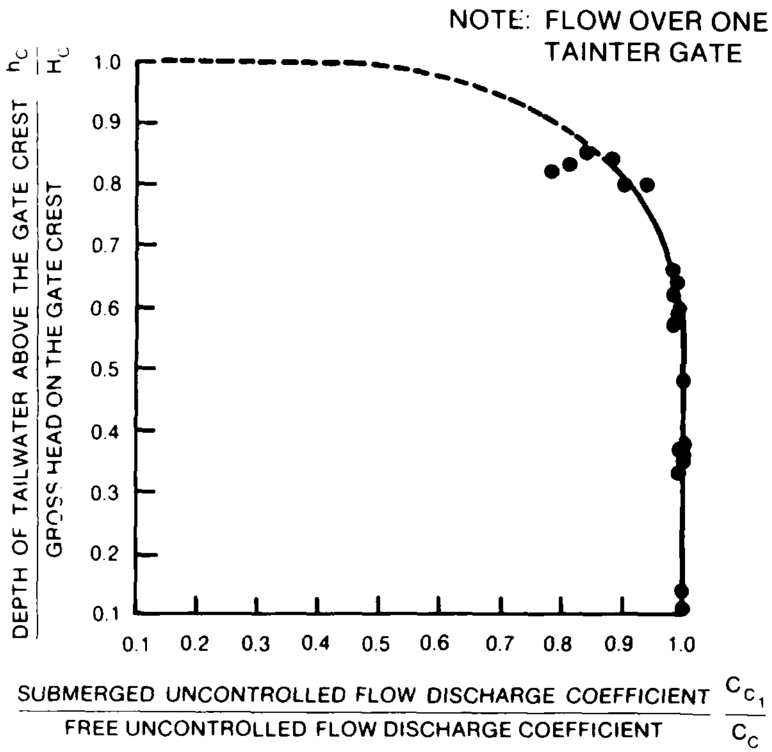
DISCHARGE COEFFICIENTS
FOR SUBMERGED UNCONTROLLED FLOW
TYPE 2 SPILLWAY CREST



DISCHARGE COEFFICIENTS
FOR FREE UNCONTROLLED FLOW
OVER GATE
TYPE 1 SPILLWAY CREST

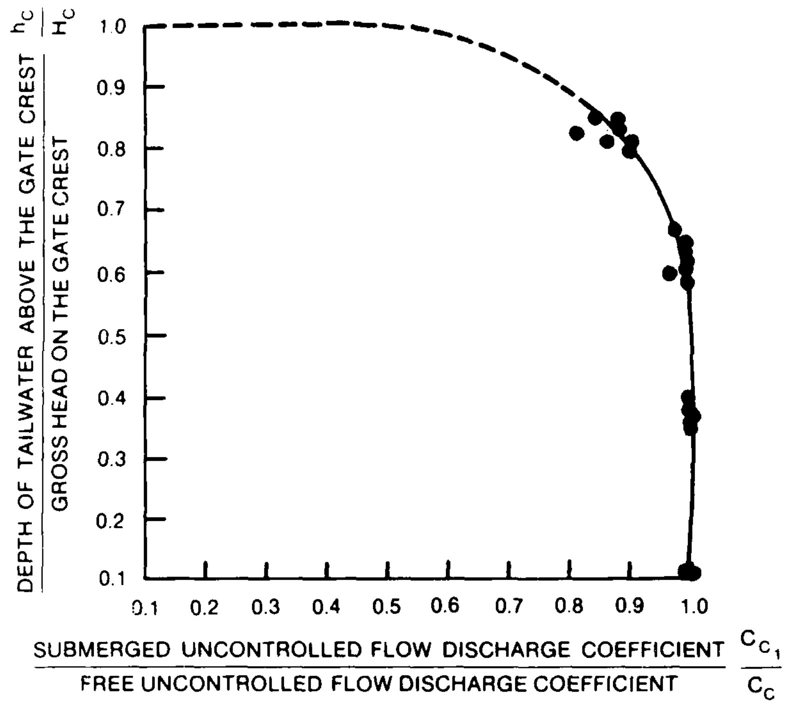


DISCHARGE COEFFICIENTS FOR FREE UNCONTROLLED FLOW OVER GATE TYPE 2 SPILLWAY CREST

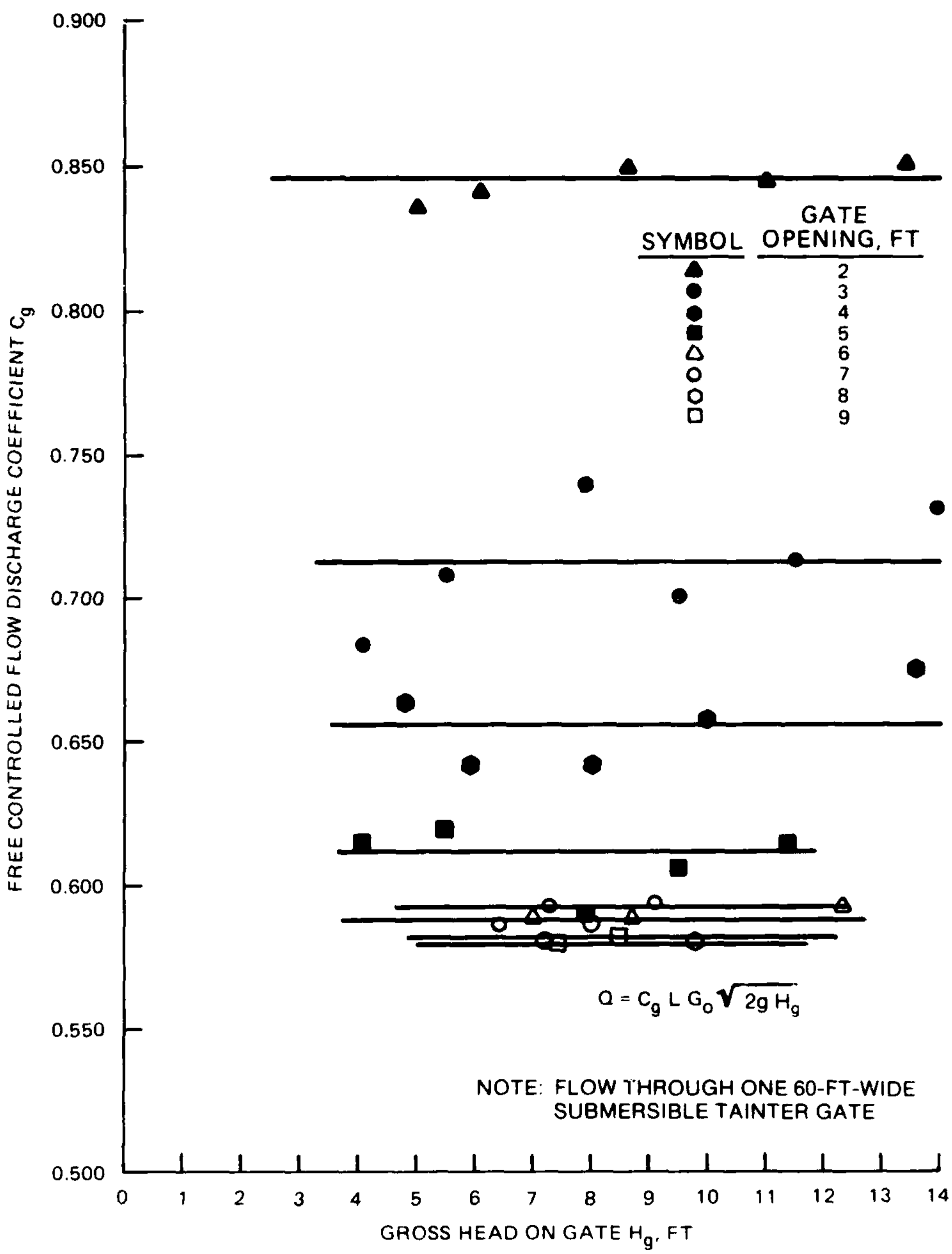


**DISCHARGE COEFFICIENTS
FOR SUBMERGED UNCONTROLLED FLOW
OVER GATE
TYPE 1 SPILLWAY CREST**

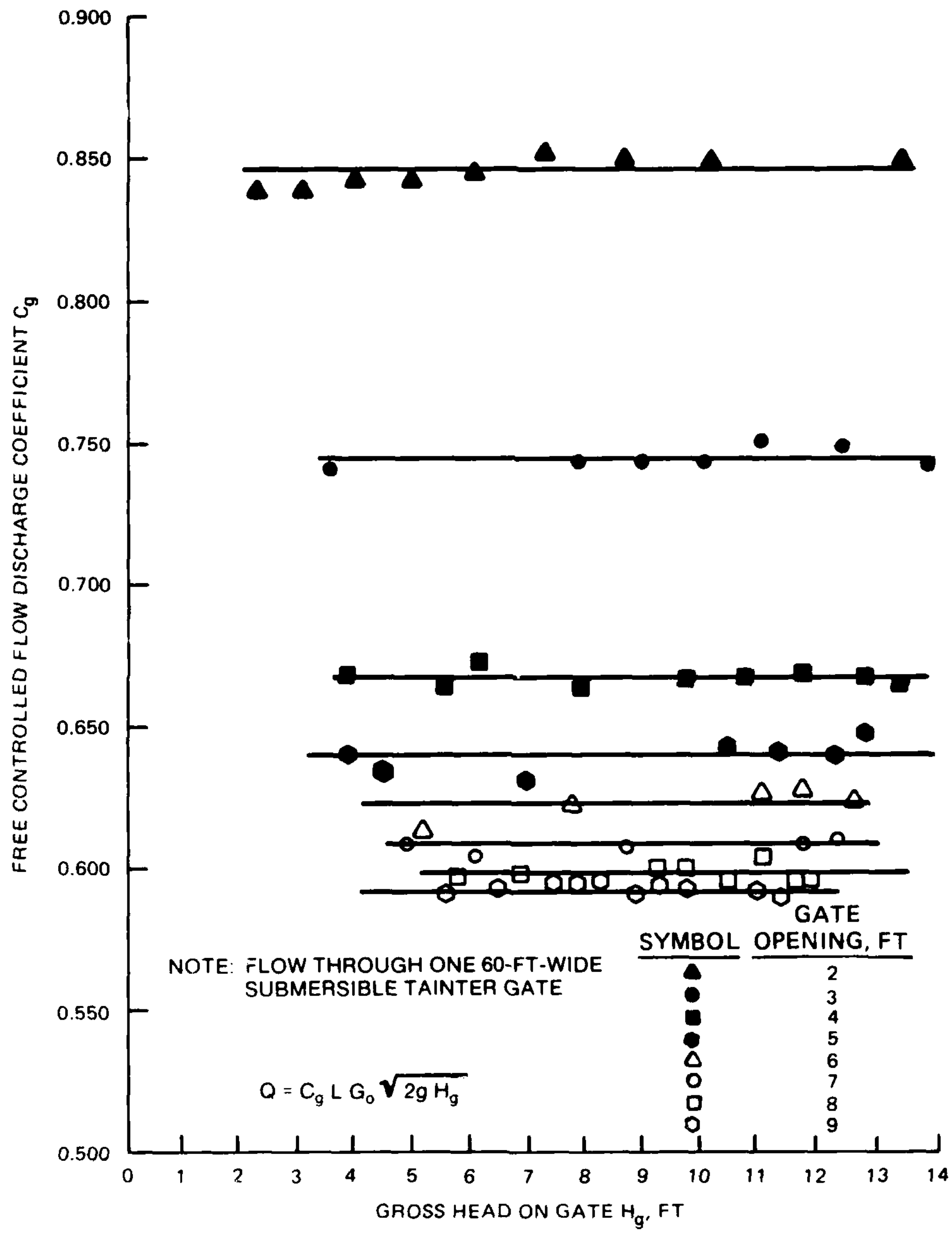
NOTE: FLOW OVER ONE SUBMERSIBLE TAINTER GATE



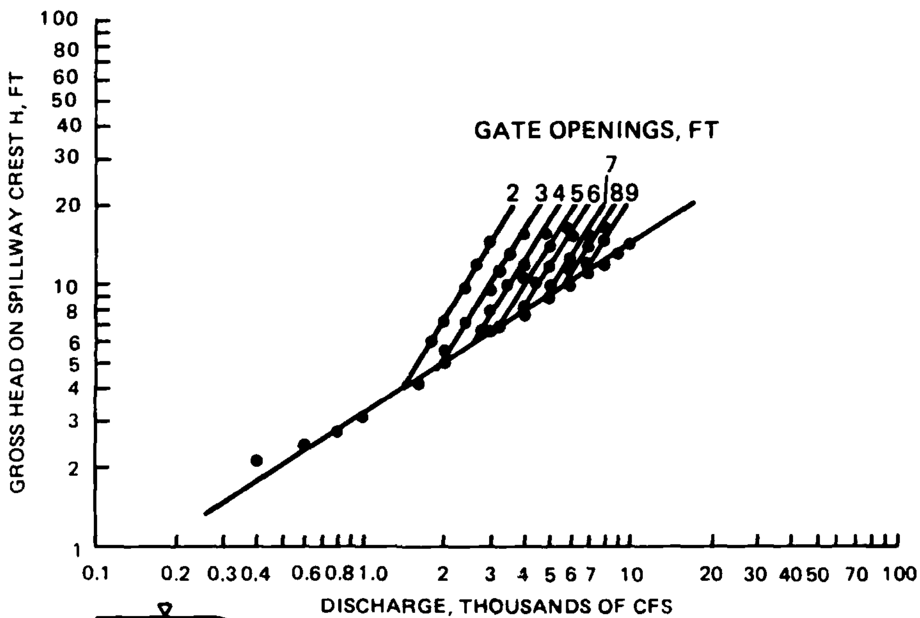
DISCHARGE COEFFICIENTS
FOR SUBMERGED UNCONTROLLED FLOW
OVER GATE
TYPE 2 SPILLWAY CREST

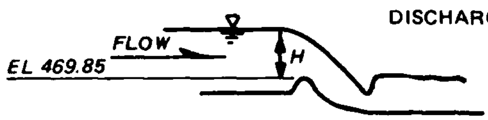


DISCHARGE COEFFICIENTS FOR FREE CONTROLLED FLOW TYPE 1 SPILLWAY CREST



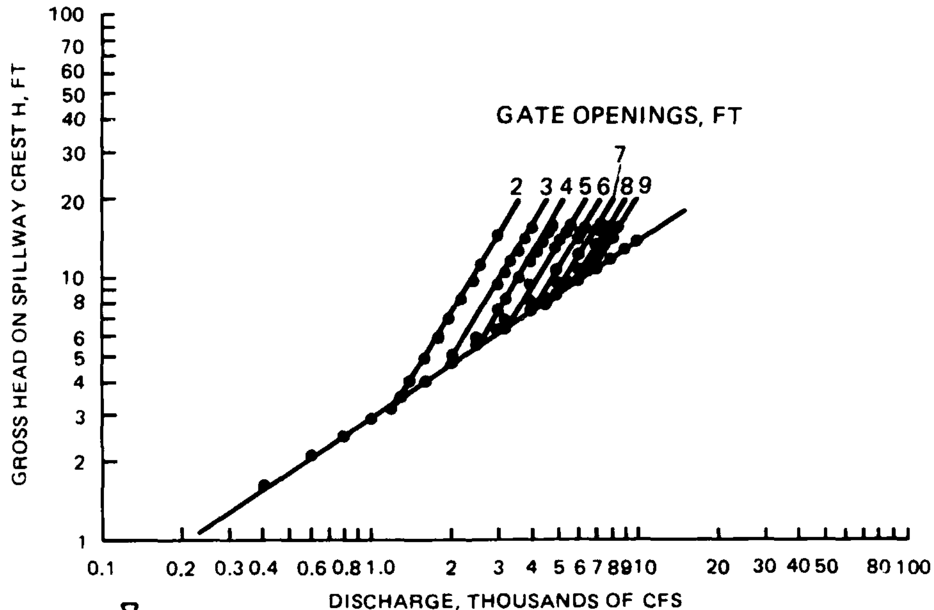
DISCHARGE COEFFICIENTS FOR FREE CONTROLLED FLOW TYPE 2 SPILLWAY CREST

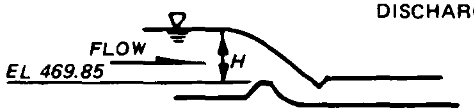




TYPE 1 SPILLWAY CREST

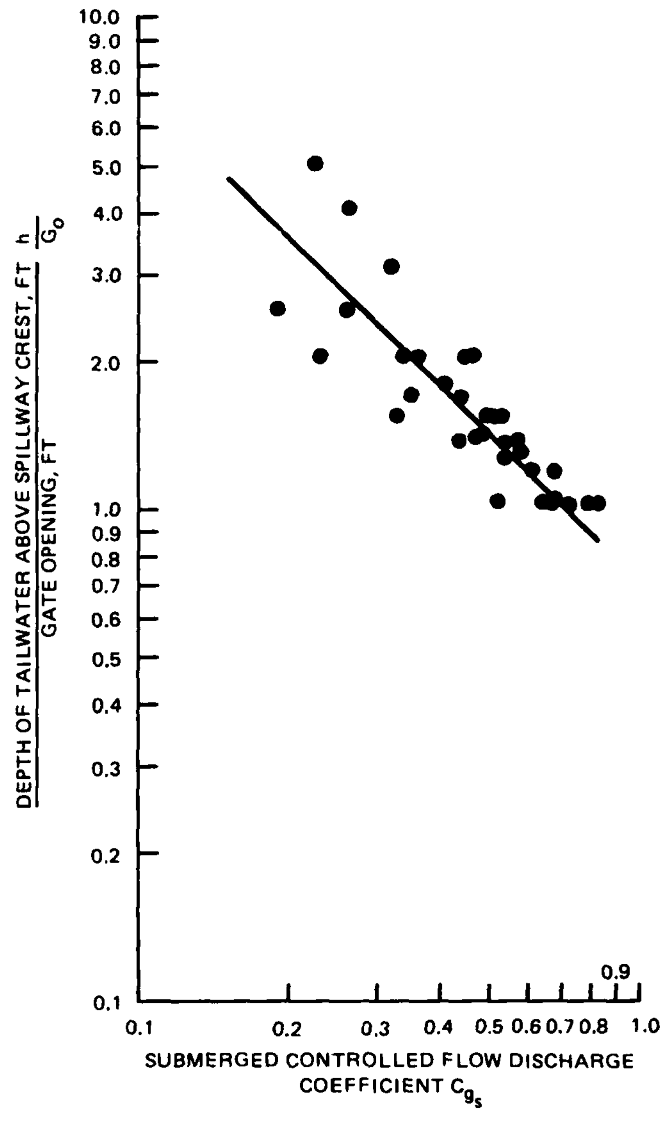
DISCHARGE-HEAD RELATION
FOR FREE FLOW
TYPE 1 SPILLWAY CREST



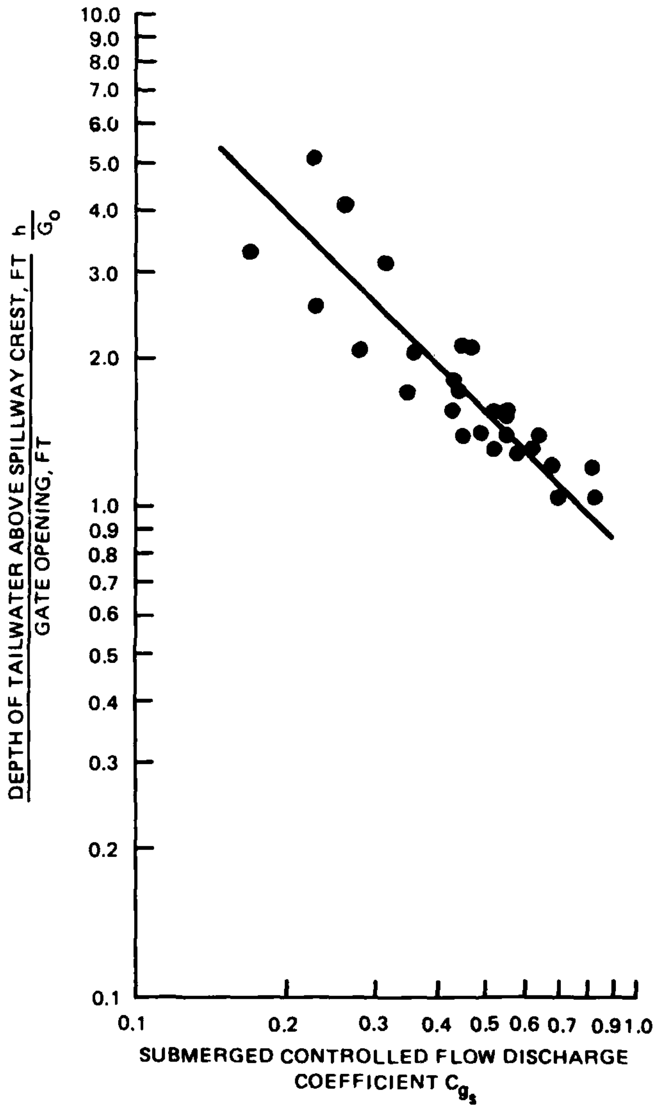


TYPE 2 SPILLWAY CREST

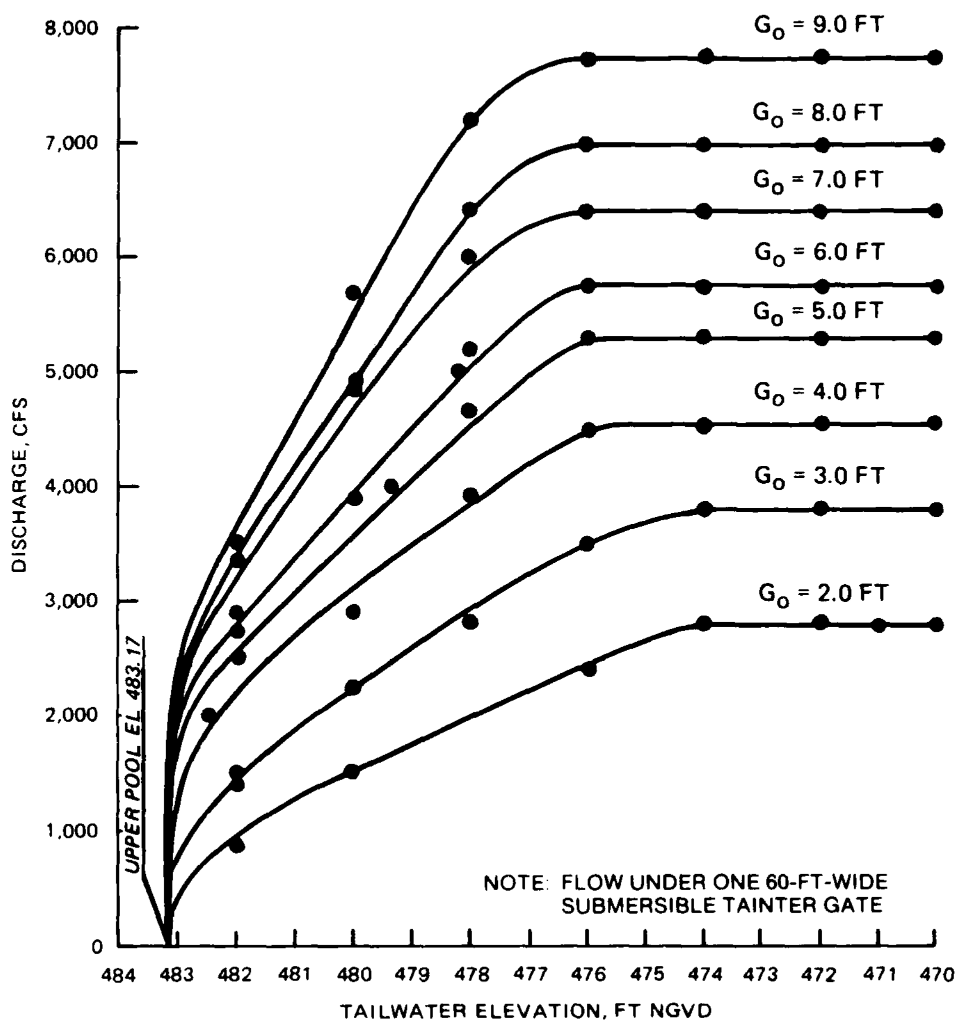
DISCHARGE-HEAD RELATION FOR FREE FLOW TYPE 2 SPILLWAY CREST



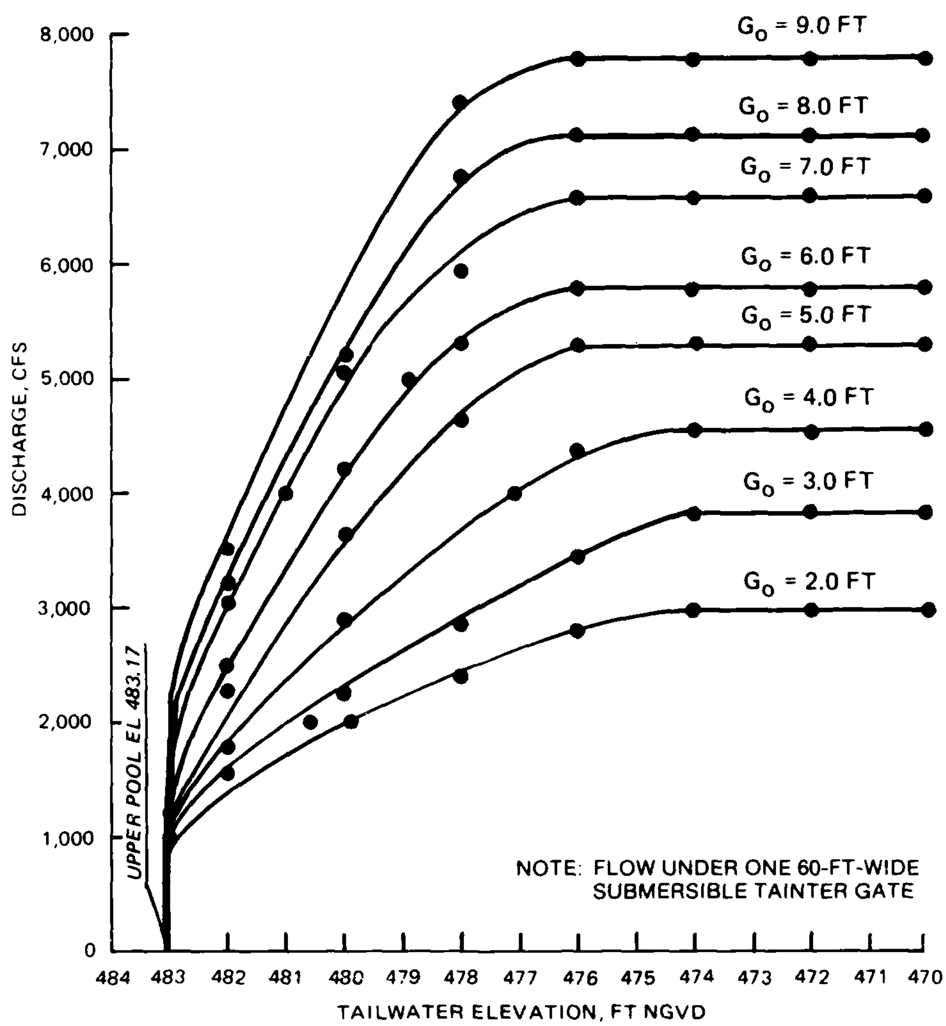
DISCHARGE COEFFICIENTS FOR SUBMERGED CONTROLLED FLOW TYPE 1 SPILLWAY CREST



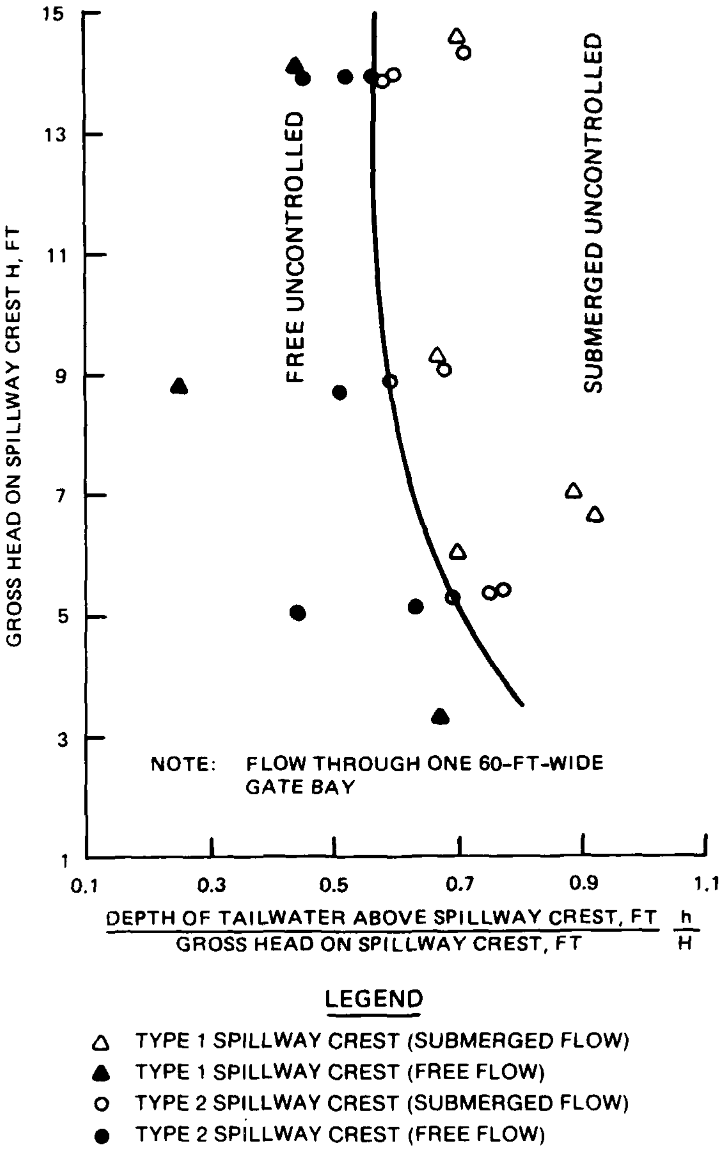
DISCHARGE COEFFICIENTS
FOR SUBMERGED CONTROLLED FLOW
TYPE 2 SPILLWAY CREST



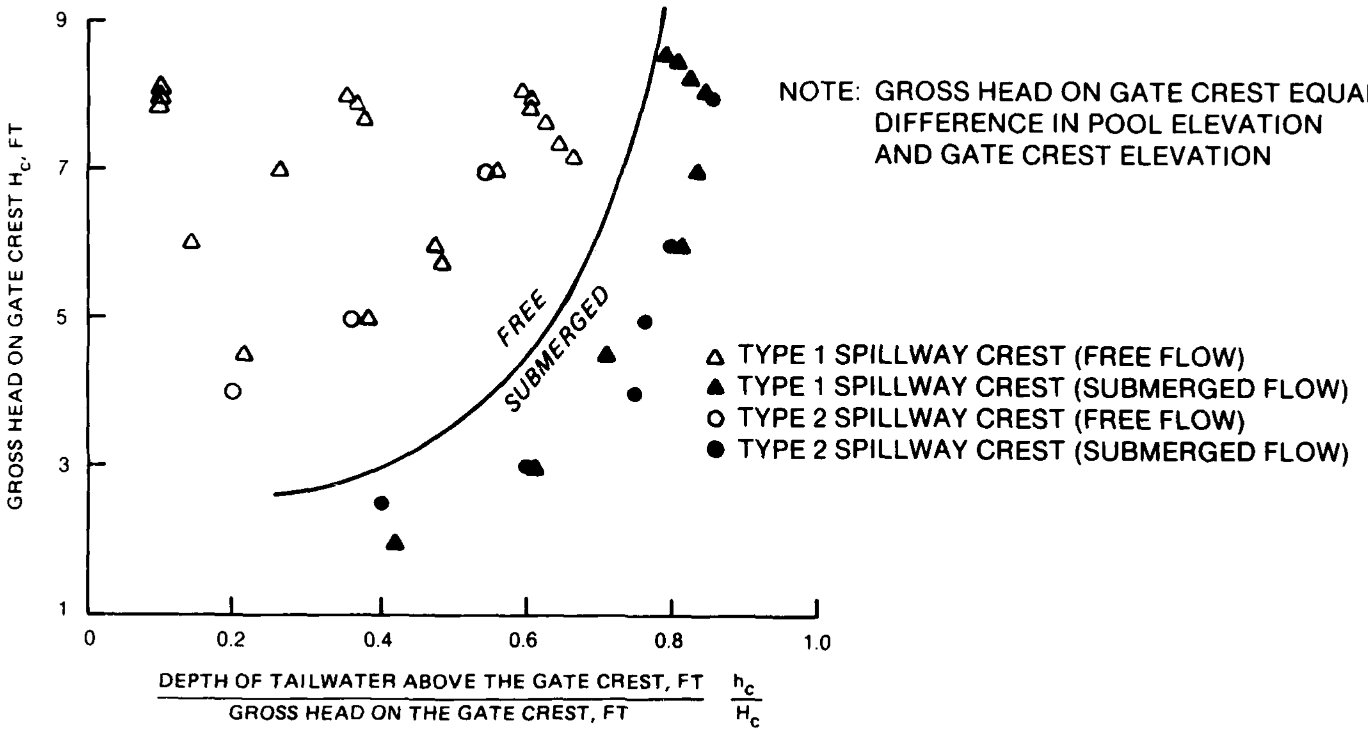
EFFECT OF TAILWATER ELEVATION ON DISCHARGE TYPE 1 SPILLWAY CREST



EFFECT OF TAILWATER ELEVATION ON DISCHARGE TYPE 2 SPILLWAY CREST

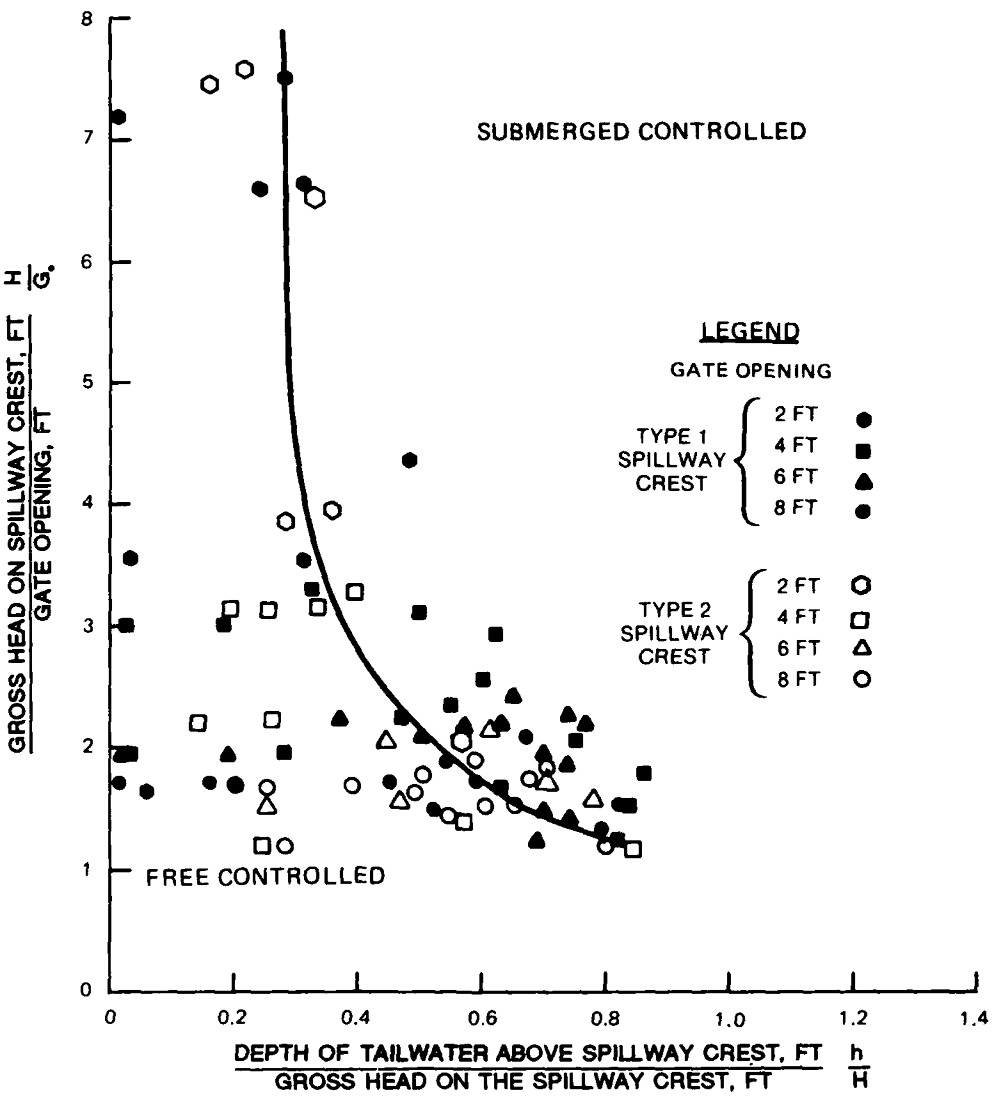


UNCONTROLLED FLOW REGIMES FOR FLOW OVER SPILLWAY TYPES 1 AND 2 SPILLWAY CRESTS



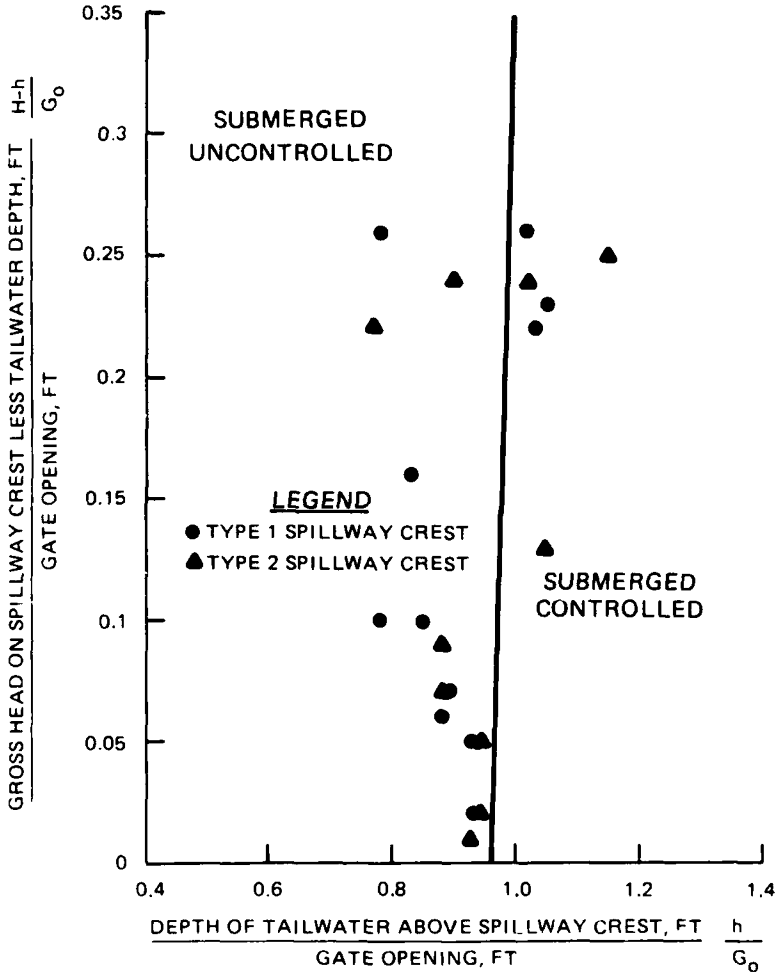
NOTE: GROSS HEAD ON GATE CREST EQUALS DIFFERENCE IN POOL ELEVATION AND GATE CREST ELEVATION

**UNCONTROLLED FLOW REGIMES
FOR FLOW OVER GATE
TYPES 1 AND 2 SPILLWAY CRESTS**



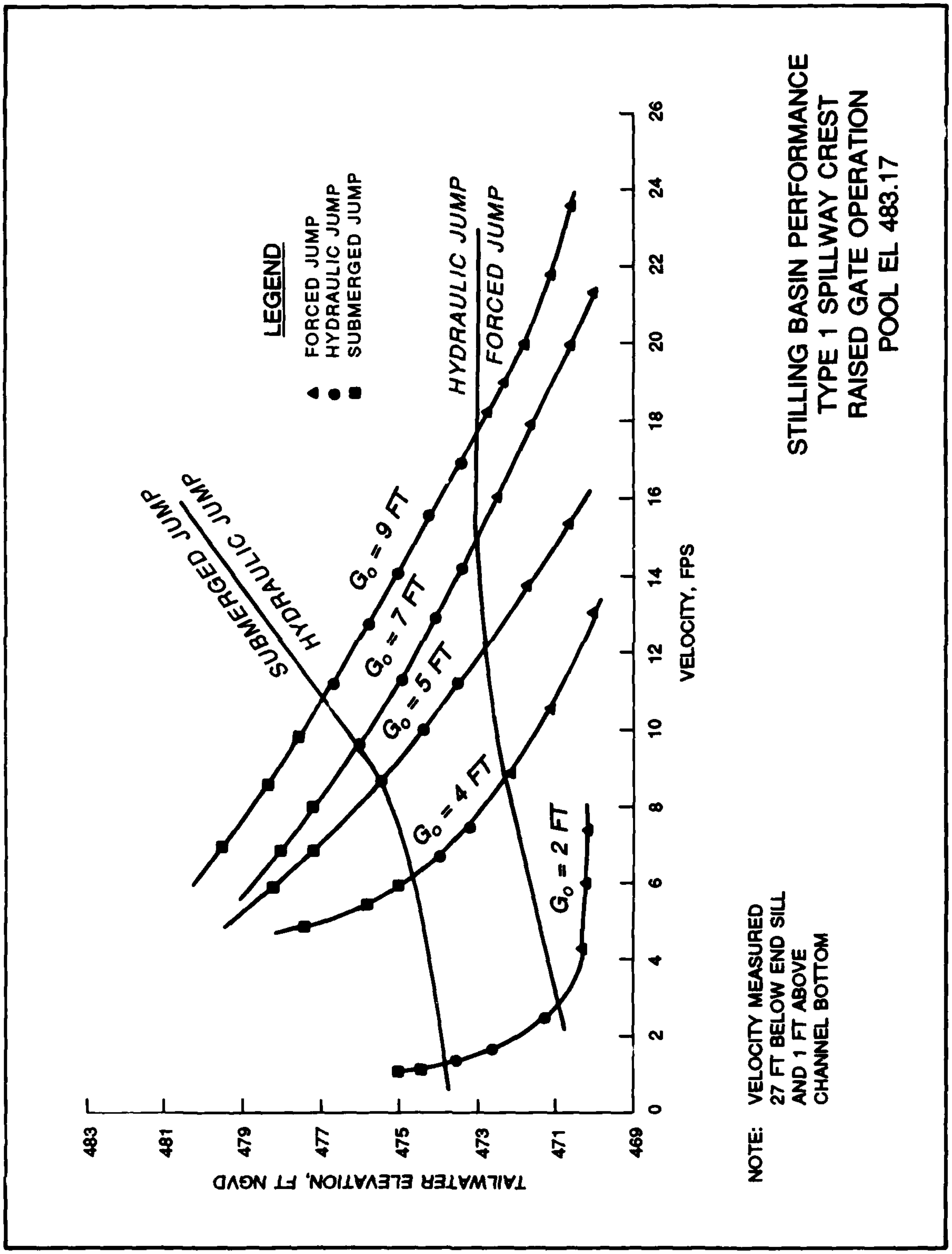
NOTE: FLOW UNDER ONE 60-FT-WIDE SUBMERSIBLE TAINTER GATE

CONTROLLED FLOW REGIMES
TYPES 1 AND 2 SPILLWAY CRESTS

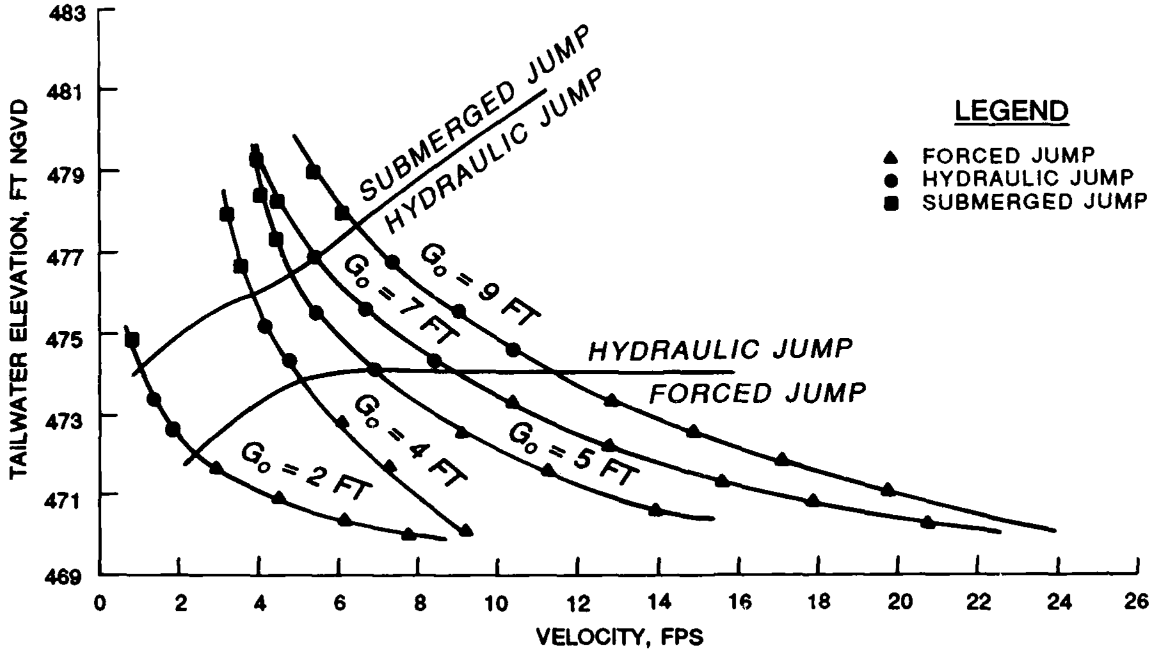


NOTE: FLOW UNDER ONE 60-FT-WIDE SUBMERSIBLE TAINTER GATE

SUBMERGED FLOW REGIMES

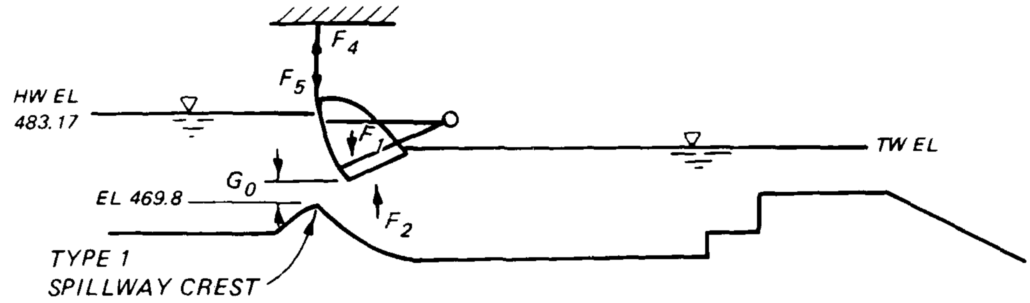


STILLING BASIN PERFORMANCE
TYPE 1 SPILLWAY CREST
RAISED GATE OPERATION
POOL EL 483.17
LEGEND
▲ FORCED JUMP
● HYDRAULIC JUMP
■ SUBMERGED JUMP
TAILWATER ELEVATION, FT NGVD
VELOCITY, FPS
SUBMERGED JUMP
HYDRAULIC JUMP
HYDRAULIC JUMP
FORCED JUMP
G_o = 9 FT
G_o = 7 FT
G_o = 5 FT
G_o = 4 FT
G_o = 2 FT
483
481
479
477
475
473
471
469
0
2
4
6
8
10
12
14
16
18
20
22
24
26
NOTE: VELOCITY MEASURED
27 FT BELOW END SILL
AND 1 FT ABOVE
CHANNEL BOTTOM

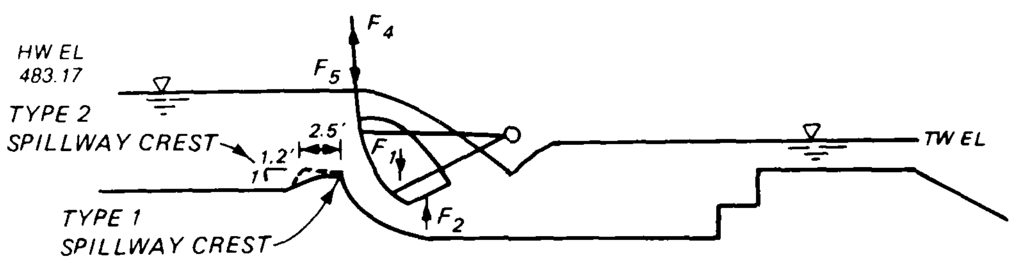


NOTE: VELOCITY MEASURED 27 FT BELOW END SILL AND 1 FT ABOVE CHANNEL BOTTOM

STILLING BASIN PERFORMANCE
TYPE 2 SPILLWAY CREST
RAISED GATE OPERATION
POOL EL 483.17



RAISED GATE
DEFINITION SKETCH

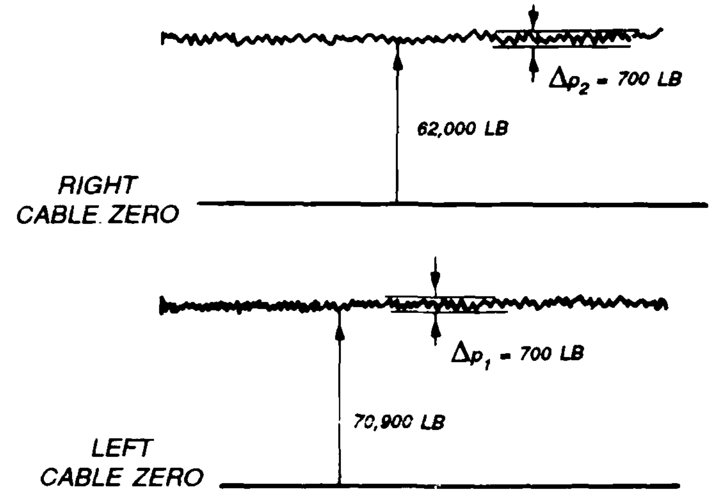


SUBMERGED GATE
DEFINITION SKETCH

DEFINITION OF TERMS:

F_1 - DRY WEIGHT OF GATE SUPPORTED BY CABLES, LB
F_2 - TAILWATER DISPLACED BY GATE, LB
F_4 - MEASURED MAXIMUM LOADS DURING TESTS, LB
F_5 - FLOW-INDUCED LOAD ON CABLES, LB
HW EL = HEADWATER ELEVATION = 483.17 FT NGVD
TW EL = TAILWATER ELEVATION, FT NGVD (VARIES)

PROFILE SKETCH
OF
MODEL OPERATION



SAMPLE OSCILLOGRAPH RECORD

SAMPLE CALCULATION

GIVEN: GATE SUBMERGENCE = 1 FT TW 470
TYPE 1 (ORIGINAL) APPROACH

F_1 = 115,300 LB

F_2 = 2,900 LB

$F_3 = F_1 - F_2$

F_3 = 115,300 - 2,900

$\boxed{F_3 = 112{,}400 \text{ LB}}$

$\boxed{F_4 = 132{,}900 \text{ LB}}$

$F_{5_{MAX}} = F_4 - F_3$

$F_{5_{MAX}}$ = 132,900-112,400

$\boxed{F_{5_{MAX}} = 20{,}500 \text{ LB}}$

$F_{5_{MIN}} = F_{5_{MAX}} - \Delta_p$

$F_{5_{MIN}}$ = 20,500 LB - 1,400 LB

$\boxed{F_{5_{MIN}} = 19{,}100 \text{ LB}}$

f = 3.4 HZ

$\Delta p = \Delta p_1 + \Delta p_2$

Δp = 700 + 700

Δp = 1,400 LB

DEFINITION OF TERMS:

$F_3 = (F_1 - F_2)$, SUBMERGED WEIGHT OF GATE SUPPORTED BY CABLES, LB

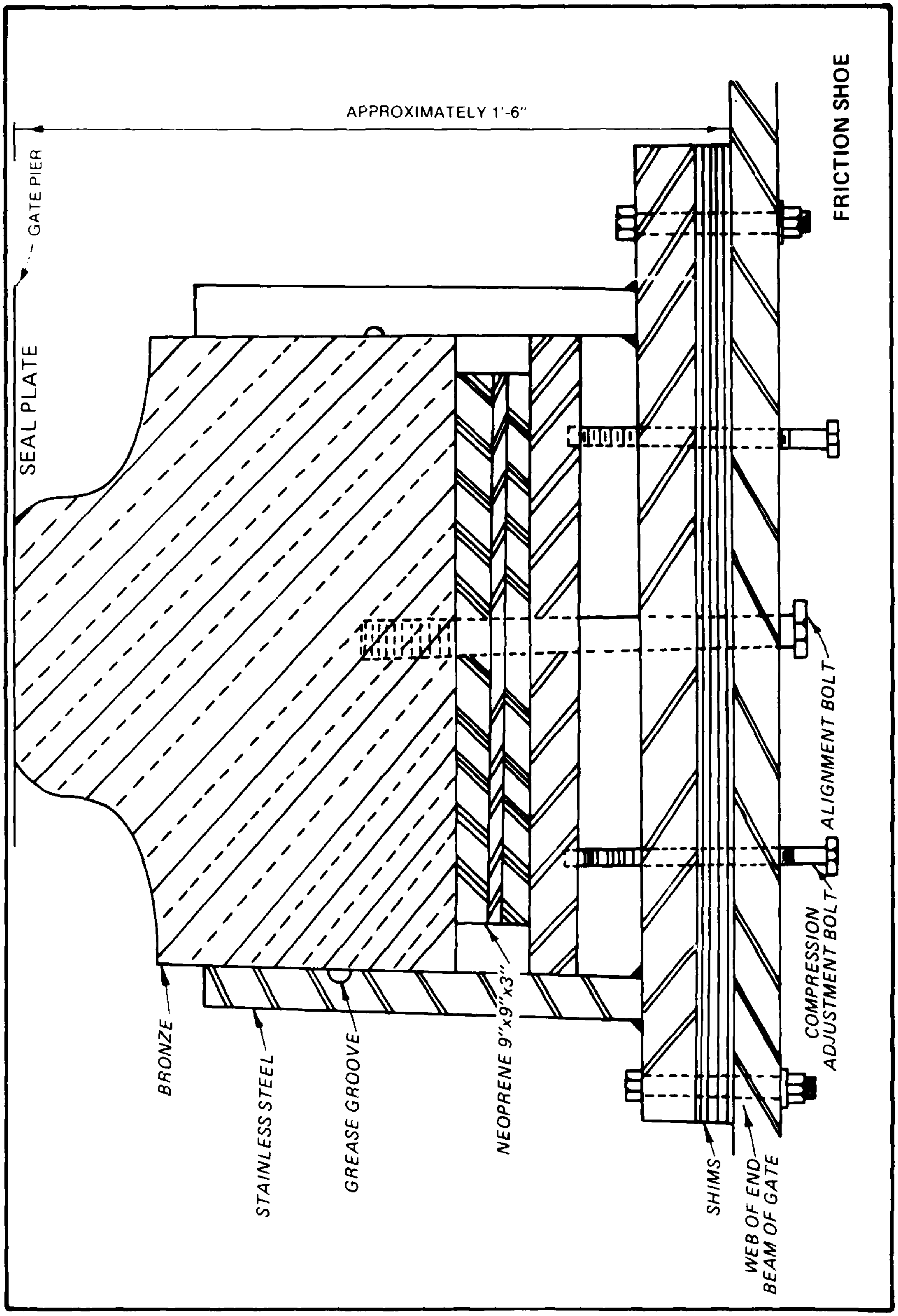
Δ_p = AMPLITUDE OF LOAD FLUCTUATIONS, LB

$F_{5_{MAX}}$ = MAXIMUM FLOW-INDUCED LOAD ON CABLES $(F_4 - F_3)$, LB

$F_{5_{MIN}}$ = MINIMUM FLOW-INDUCED LOAD ON CABLES $(F_{5_{MAX}} - \Delta_p)$, LB

f = frequency of vibration
HZ = Hertz, cyles/sec

SAMPLE FORCE CALCULATION AND OSCILLOGRAPH RECORD



APPROXIMATELY 1'-6"
GATE PIER
SEAL PLATE
FRICTION SHOE
BRONZE
STAINLESS STEEL
GREASE GROOVE
NEOPRENE 9"x9"x3"
SHIMS
WEB OF END BEAM OF GATE
COMPRESSION ADJUSTMENT BOLT
ALIGNMENT BOLT

PLATE 44